ELECTROMYOGRAPHY & ELECTRICAL STIMULATION

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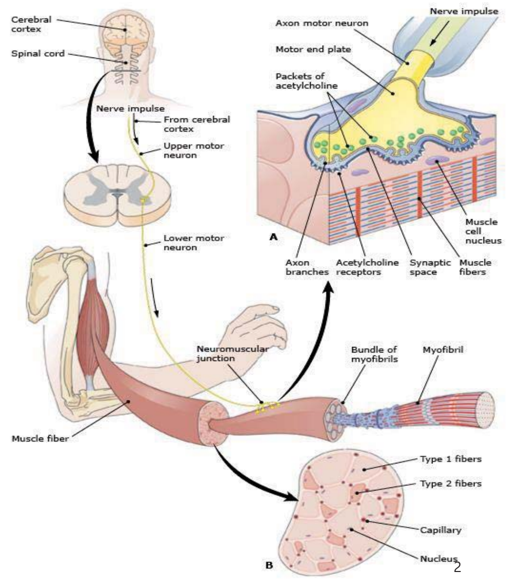
Muscle Activation

› Motor unit
  ▪ composed of one motor neuron and all the muscle fibers that it controls

› There are many motor units in a muscle

› The fewer the number of fibers per neuron → the finer the movement

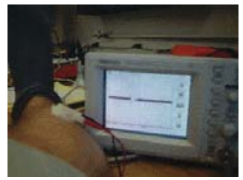


INTRODUCTION TO ELECTROMYOGRAPHY

Introduction

› Electromyogram (EMG) is a technique for evaluating and recording the activation signal of muscle fibers of activated motor units

› EMG is performed by an electromyograph, which records an electromyogram

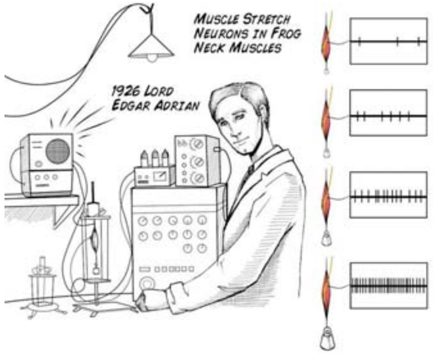


› Electromyograph detects the electrical potential generated by muscle cells when these cells contract and relax

› The study of EMG's is called electromyography

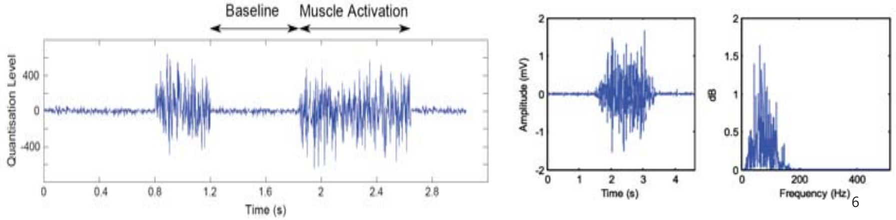
History

- 1929, Adrian devised a method to record a single motor unit potential by connecting concentric needle electrodes to an amplifier and a loud speaker
  - relaxing muscle doesn't produce voltage
  - EMG signals are generated in case of muscle contractions



Electrical Characteristics of EMG Signal

- The electrical source is the muscle membrane potential of about -70mV
- Measured EMG potentials range between < 50 μV up to 20 to 30 mV, depending on the muscle under observation
- Typical repetition rate of muscle unit firing is about 7-20 Hz



Electromyographic Instructions

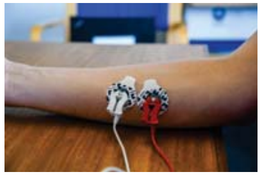
- EMG signal reflects the number and size of motor units contracting
- Needle electrodes
  - penetrate the skin and close proximity to motor units
  - specific, small, or deep muscle
- Surface electrodes
  - placed on the skin overlying the muscle
  - through less sensitive, relative comfort and noninvasiveness

Fine-wire Needle Electrodes

- Advantages
  - extremely sensitive
  - record single muscle activity
  - access to deep musculature
  - little cross-talk concern
- Disadvantages
  - extremely sensitive
  - requires medical personnel, certification
  - repositioning nearly impossible
  - detection area may not be representative of entire muscle

Surface Electrode

› Advantage
- not permanent
- good for short-term use
- reuseable
- good for nerves that aren't deep
- non-invasive



› Disadvantage
- hard to place exactly over correct area
- a hassle to put on all the time
- difficult to stimulate deep nerves
- can stimulate pain feedback nerves
- precision is low
- can cause skin burns

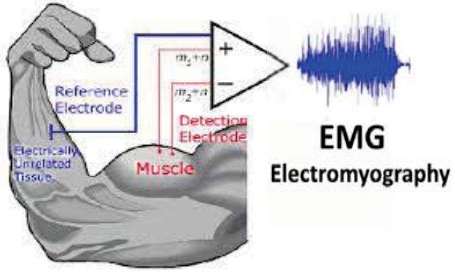
Surface EMG Procedures

› Clean the site of application of electrode

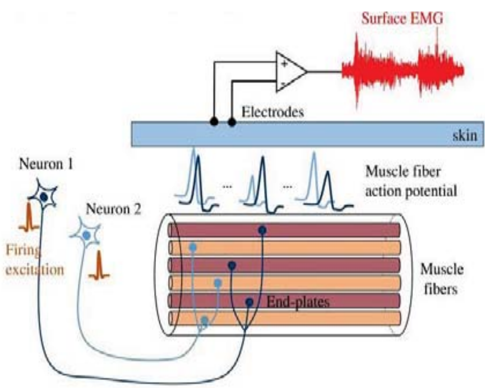
› Insert needle/place surface electrodes at muscle belly

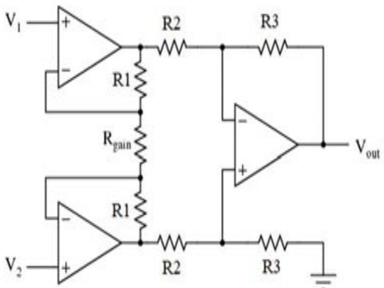
› Record muscle activity at rest

› Record muscle activity upon voluntary contraction of the muscle



EMG Circuit



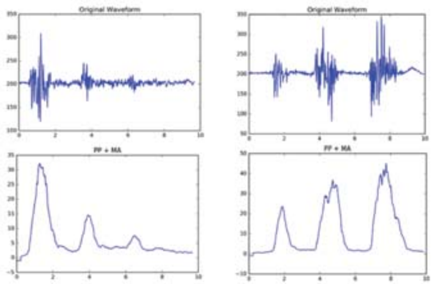


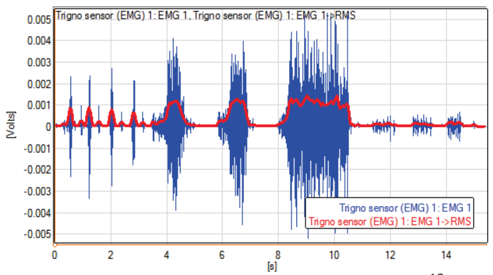
Characteristics of EMG Signal

› Amplitude range: 0–10 mV (+5 to -5) prior to amplification

› Useable energy: range of 0 - 500 Hz

› Dominant energy: 30 – 200 Hz



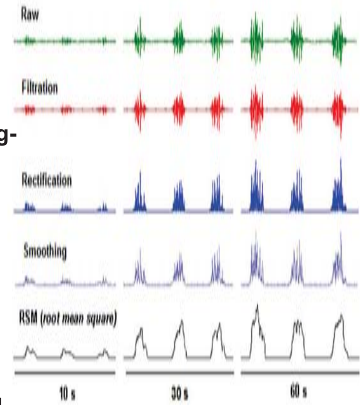


Noise Elimination for EMG Recording

- EMG devices must be designed to eliminate electrical energy from the environmental sources and display only electrical signals related to motor unit activity
  - differential amplifier
    - eliminate the environmental signals
  - electrical filters
    - eliminate high-frequency electrical noise generated by the circuits of the EMG unit itself and the low-frequency signal generated at the interference of the electrode and the gel
  - ground or common electrode
- The electrodes to measure muscle activity are placed longitudinally along the muscle belly and the common electrode may be placed preferably over a bony prominence where muscle activity is not recorded

Signal Processing for EMG

- The raw EMG signal received from a contracting muscle is an analog signal
  - not very useful for biofeedback purposes
- Processing procedure
  - analog signal convert to digital signal by analog-to-digital converter (AD, A/D, or ADC)
  - rectified signal
    - remaining on one side of baseline
  - smoothed signal
    - smooth through a filter to graph the electrical signal for the use of visual feedback
- Auditory feedback may be incorporated into treatment session
  - a threshold value was set for reeducation or strength training as well as for relaxing training

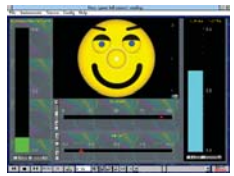


Applications of EMG

- EMG can be used for diagnosis of neurogenic or myogenic diseases
- Indicator for muscle activation/deactivation
- Relationship of force/EMG signal
- Use of EMG signal as a fatigue index

Muscle Reeducation and Strengthening

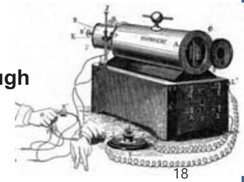
- EMG biofeedback is used to reeducate weak or flaccid muscles and to strengthen muscle
  - electrodes should be large and widely spaced to pick up any signal emitted by the weak muscle
  - as patient improves, the electrodes should be smaller and placed closer together
  - an attainable auditory threshold is set and the patient is encouraged to contract the muscle enough to reach the threshold
  - during the treatment session, the threshold is gradually raised to encourage stronger muscle contraction
  - as soon as possible, the patient should be weaned from EMG biofeedback by incorporating the movement or strength attained into purposeful activities



INTRODUCTION TO ELECTRICAL STIMULATION

The Start of Electrotherapy

- Guillaume Benjamin Amand Duchenne (1806-1875)
  - a French neurologist
    - considered the father of electrotherapy
    - began in the 1840s to use the induction coil to extensively study muscles and paralysis
  - discovered that a movement (raising a finger, moving the arm in a certain direction, creating a smile) was usually not caused by the contraction of just one muscle but rather required coordination between a number of muscles
    - by passing the high voltage from the induction coil through a muscle (which he called "localized faradization") and seeing what sort of movement its contraction caused



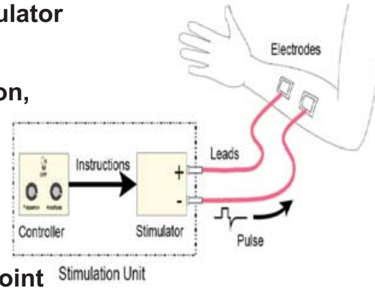
(from http://chem.ch.huji.ac.il/history/duchenne.html)

Therapeutic Electrical Stimulation

- Neuromuscular electrical stimulation (NMES)
  - the application of electrical current to elicit a muscular contraction
  - use for orthopedic and neuromuscular rehabilitation
- Functional Electrical Stimulation (FES)
  - technique uses low electrical currents to restore body function in people with disabilities by stimulating nerves
    - innervating extremities affected by paralysis resulting from spinal cord injury (SCI), head injury, cerebral palsy, stroke or other neurological disorders

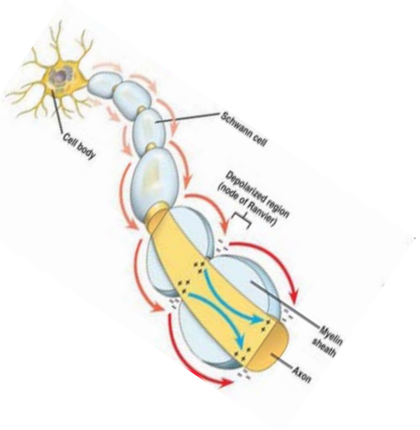
Basic FES System

- Electrodes
  - interfaces between the electrical stimulator and the nervous system
  - can be external (surface) or surgically implanted depending on the application, device, and the patient's needs
- Leads
- Stimulator
- Controller
  - include joysticks, buttons, switches, joint positions sensors, heel switches, sip-and-puff devices, EMG electrodes, and voice activation



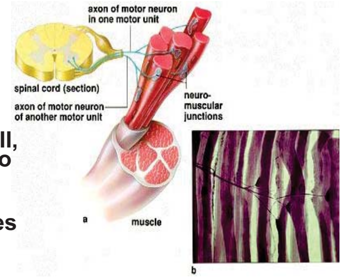
Propagation of Action Potential

- "All or none" behavior
  - a rule of the neuron in that action potentials will always be of the same size and are only generated if the threshold level is reached
- Effects of size principle
  - intracellular stimulation
    - small cell is excited first
  - extracellular stimulation
    - large cell is excited first



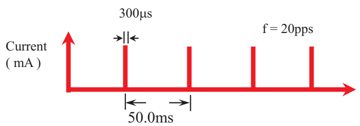
Recruitment of Motor Unit

- Voluntary muscle contraction
  - smaller motor units composed of primary Type I, fatigue-resistant fibers tend to be recruit first
  - different motor units are recruited asynchronously
  - constant tension of muscle is maintained
- Electrical excitation
  - larger motor units composed of primary Type II, readily fatigable fibers are recruited first due to lower threshold
  - motor units of similar threshold lying superficially beneath the stimulating electrodes will be recruited simultaneously
  - as the muscle fatigue
    - tension will begin to decrease unless the intensity of the stimulus is increase or recruiting additional motor units with higher thresholds



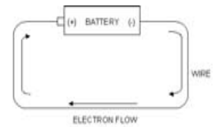
Principle of Application

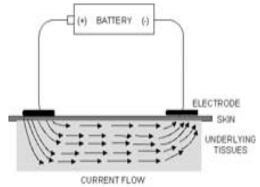
- Electrode systems
- Electrical stimulus
  - polarity
  - waveforms
  - amplitude (intensity)
  - phase duration
  - frequency (pulse rate)
  - duty cycle
  - ramp time



Electrical Stimulus- Polarity

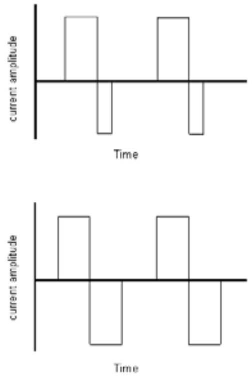
- Electron flow from cathode to anode
- Current flow from anode to cathode
- Pfleüger's law
  - under normal physiological conditions, less current is required from a cathodal (negative) stimulus to evoke a muscle contraction of given strength than an anodal (positive) stimulus
    - negative electrode, the active electrode, is often used to evoke the muscle contraction
    - anode electrode is often termed the inactive, reference, or dispersive electrode





Electrical Stimulus- Waveforms and Amplitude

- Waveforms allow an equal amount of current to flow in either phase, thus avoiding undesirable electrochemical effects and possible skin irritation
  - asymmetrical biphasic square wave
    - allow selective recruitment of smaller muscles
    - tissue irritants can accumulate under one of the electrodes if asymmetrical biphasic waveform is unbalanced resulting in a burning or itching sensation under the electrodes
      - accumulation of charge occurs
  - symmetrical biphasic square wave
    - prefer for stimulation of large muscle groups
- As amplitude is increased there is an increase in the number of motor units recruited, an increase in the muscle force developed
  - most device have a maximum output of 100 mA

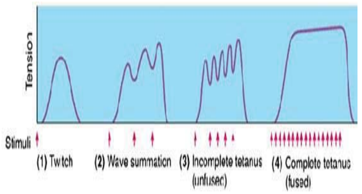


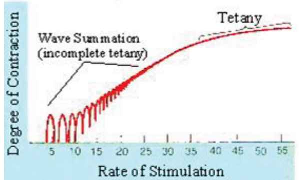
Electrical Stimulus- Phase Duration

- Many ES devices have a fixe-phase duration of between 0.2 and 0.4 ms
  - the development of muscle force can be adjusted from the point at which a muscle contraction just begins to near maximal force by merely varying current amplitude
  - preferred for comfort
- Narrower phase duration (e.g., 0.05 ms)
  - require greater amplitude of current to produce a pulse charge sufficient to generate a muscle contraction
    - increased amplitude recruits small diameter afferent fibers that elicit a painful sensation
- Wider phase duration (e.g., 1.0 ms)
  - generate a pulse charge sufficient to recruit both motor and pain-sensitive axons

Electrical Stimulus- Frequency

- The rate at which the individual pulses are delivered and is measured in pulses per second (pps) or Hz
- Low frequency (1 to 5 pps)
  - generate twitch contractions, allow little sustained tension to develop in the muscle
  - used to locate motor points
- High frequency (10 to 20 pps)
  - cause a vibration or fasciculating contraction of the muscle, incomplete tetany
  - allow the most force to be generated in the muscle



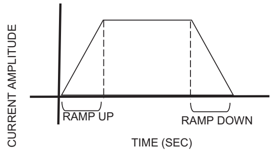


Electrical Stimulus- Duty Cycle

- To ensure that the muscle does not fatigue excessively and to effectively exercise the target muscle, the electrical stimulation may be automatically turned on and off
  - on and off time are often expressed as a ratio
    - i.e., 10 seconds on and 20 seconds off can be noted as a ratio of 1:2
- Duty cycle
  - pulse-train duration×100/total cycle time
  - a 1:5 ratio may be appropriate starting point for a patient with hemiparesis
  - a 1:3 ratio is commonly used for patients with orthopedic problems

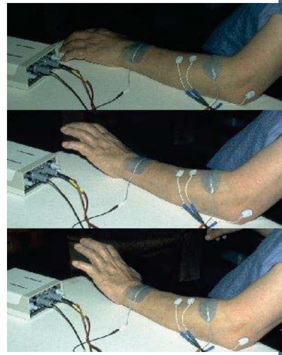
Electrical Stimulus- Ramp Time

- Use to produce a soft start, allowing the patient to become accustomed to the stimulation as t rises from nonperceptible level to sensory and finally motor thresholds
- As the cessation of the train of pulses, the fall time allows the muscle contraction to gradually relax, producing a contraction that may more closely mimic some voluntary contractions



Muscle Reeducation and Strengthening

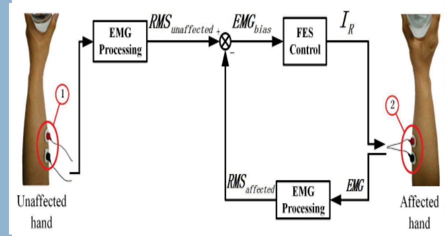
- Facilitation techniques may also be employed during the EMG biofeedback session to encourage initial motor unit activity or to increase motor unit recruitment
- Neuromuscular electrical stimulation (NMES)
  - the application of electrical stimuli to a group of muscles, most often for the purpose of muscle rehabilitation
- Dual units (EMG with NMES) are available to allow NMES activation of additional motor unit once the patient attains a specific EMG threshold during initial motor unit recruitment

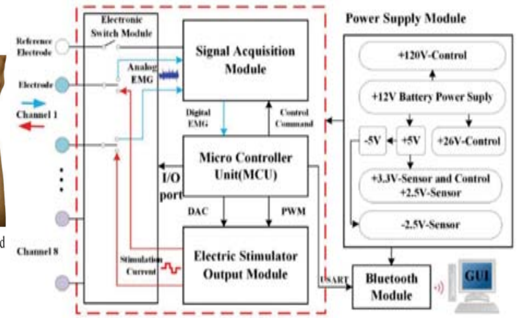


SYSTEMS INTEGRATION

sEMG Bias-driven FES Control Strategy

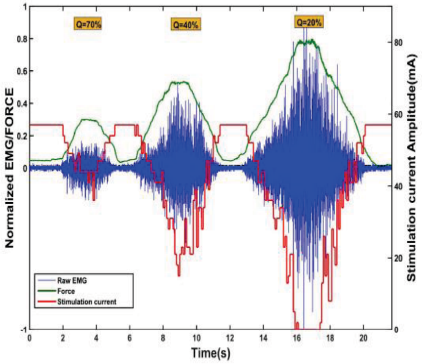
- Volitional sEMG signals corresponding to the targeted mirror symmetry muscles of bilateral arms

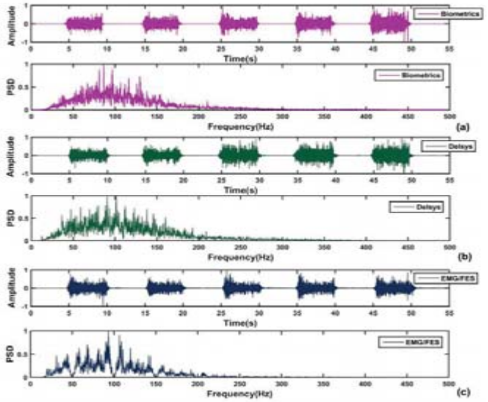




(Zhou et al., IEEE Sensors J, 2018)

Signals Comparison between the EMG/FES System

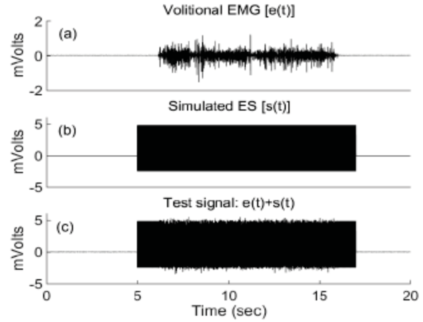




(Zhou et al., IEEE Sensors J, 2018)

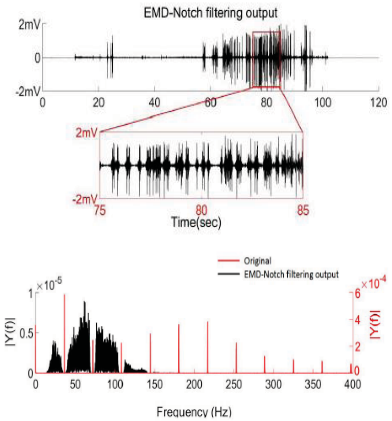
Challenge in EMG Acquired with ES

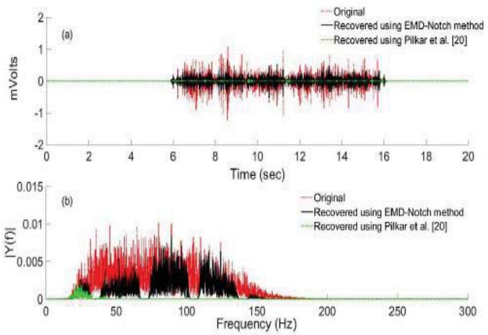
- Stimulus artifact
  - a broad band signal with wide-spread stimulus frequency harmonics at high amplitude that completely engulfs the EMG
- Challenge due to the overlapping power spectra of the ES stimulus and EMG signal



(Pilkar et al., IEEE Trans Neural Rehab Eng, 2017)

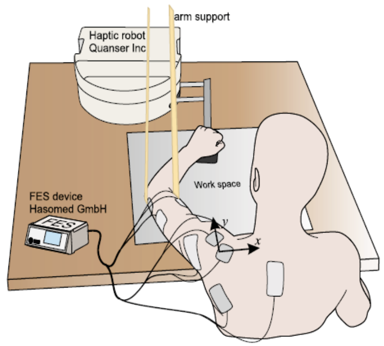
Data Filtered from ES Contaminated EMG

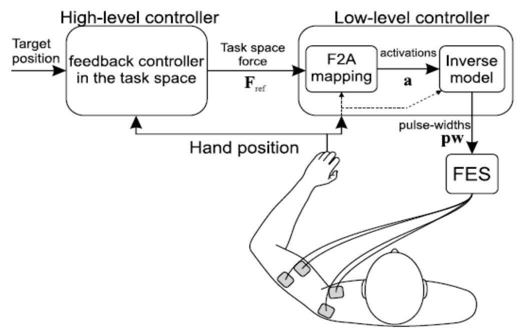




(Pilkar et al., IEEE Trans Neural Rehab Eng, 2017)

Feedback Control of FES for Arm Reaching

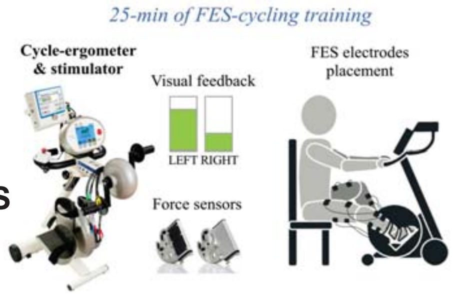




(Razavian et al., IEEE Trans Neural Sys Rehabil Eng, 2019)

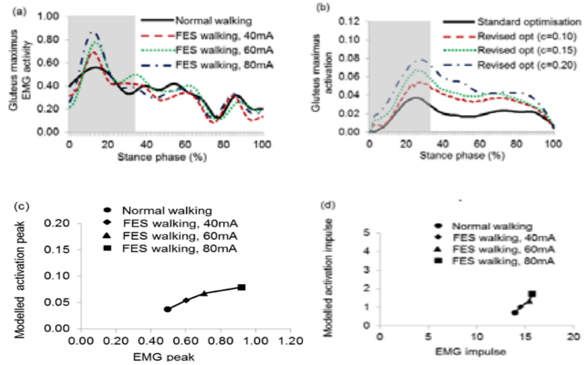
Changes of Muscle Synergies in FES-Augmented Cycling

- FES cycling training provided positively influencing neural plasticity after stroke
- Application well suits with FES-based interventions can be used to design a FES controller applied during a gait intervention



(Ambrosini et al. J. NeuroEng. Rehab., 2020)

Musculoskeletal Gait Model to Study the Role of FES



(Ding et al., IEEE Trans Biomed Eng, 2019)