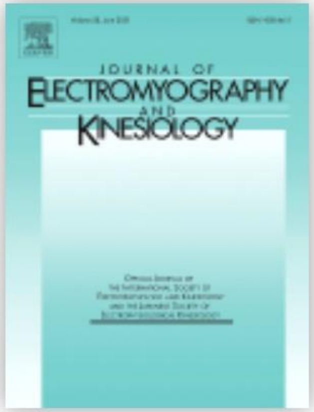


Tuesday, July 20, 2021, 1:00pm- UTC
(Coordinated Universal Time)

Surface EMG detection in space and time, conditioning and pre-processing

Introduction
R Merletti, LISiN, Politecnico di Torino, Italy. 10 min

Surface EMG detection in space and time: best practices
S. Muceli, Chalmers University of Technology, Sweden. 30 min +10 min. disc.

EMG detection, conditioning and pre-processing: best practices
GL Cerone, LISiN, Politecnico di Torino. 30 min +10 min. disc.

This webinar is oriented to non-engineers and clinical operators.
It is based on the first two Tutorials published in the Journal of Electromyography and Kinesiology and concerning surface EMG.

In the last few decades great developments have taken place in the sEMG field.

They concern signal processing and information extraction about the muscle drive, muscle coordination, electrodes, signal detection and conditioning, etc.

Greater efforts in technology transfer, teaching, and user education are necessary and are under way in most countries. They are aimed to movement and sport scientists, rehabilitation clinicians, and ergonomists.

Recent international initiatives in the educational field:

1. Project COMES (2016-2021):

Movement control and non-invasive electromyography: development of models and web clinical teaching tools.
Teaching material available in https://www.robertomerletti.it/en/emg/material/teaching/ , Torino, Italy.
10 teaching modules, over 500 slides. Free access and download.

2. Tutorials published in the J. of Electrom. and Kinesology (2018-….):

a) Merletti R., Muceli S., Tutorial. Surface EMG detection in space and time: best practices. Journ. of Electromyogr. and Kinesiol., 2019; 49: doi.org/10.1016/j.jelekin.2019.102363 (open access)

b) Merletti R., Cerone G.L. Tutorial. Surface EMG detection, conditioning and pre-processing: best practices, Journ. of Electromyogr. and Kinesiol., 2020; 54 102440, doi:10.1016/j.jelekin.2020.102440

3. Consensus for Experimental Design in Electromyography: CEDE Project:

Consensus for Experimental Design in Electromyography (CEDE).
A series of consensus papers have been published on the JEK.

4. Fontiers Editorial Project and Open e-Book (2019-2021):

“Surface Electromyography: Barriers limiting widespread use of sEMG in clinical assessment and neurorehabilitation.” https://www.frontiersin.org/research-topics/11157 Over 44000 visits and 9000 downloads.

isek International Society of Electrophysiology and Kinesiology

A starting point in 2016 : The COMES Project.

An on-line teaching initiative promoted by Politecnico di Torino, Italian Association of Physiotherapists, Italian Physiotherapy Society, Northwestern University, University of Birmingham.

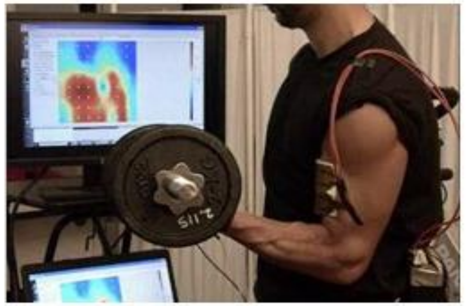
Prof. R. Merletti
Dr. V. Devecchi (physiotherapist)
Dr. K. Leskaj (physiotherapist)
Dr. R. Panero (physiotherapist)

Dr. A. Anselmino (physiotherapist)

Objectives

Rehabilitation medicine, technology and engineering are undergoing a major revolution which will deeply affect clinical practice as well as the role and the training of physical therapists. One aspect of this revolution concerns the use, understanding, application and interpretation of biomechanical and surface electromyography (sEMG) information. This project focuses on the preparation of on-line teaching material designed for, and in cooperation with, physiotherapists and movement scientists.

Biomechanics and muscle electrophysiology are fundamental pillars of training in modern prevention and rehabilitation sciences. There will be no clinical or useful technological progress without innovation in the education of engineers and clinical operators in these fields.



Activation of the biceps brachii during a concentric contraction. The short and long head of the biceps can be distinguished on the computer screen.
Longitudinal differential detection
Electrode grid of 8x8 electrodes.
Interelectrode distance = 10mm

Partners

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Politecnico di Torino
marco.gazzoni@polito.it
roberto.merletti@polito.it

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Theresa Sukal-Moulton, PT, DPT, PhD
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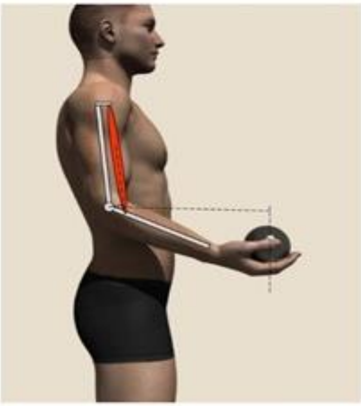
https://piemontevalledaosta.aifi.net/

SIF Società Italiana di Fisioterapia



Movement control and non-invasive electromyography: development of models and web clinical teaching tools

LISiN
Laboratory for Engineering of the Neuromuscular System, Department of Electronics and Telecomunications, Politecnico di Torino
Corso Castelfidardo 42A
10129 Torino, Italy

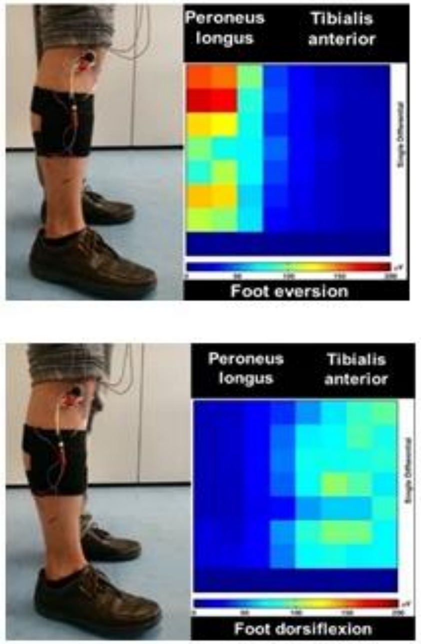
The material is aimed to non-engineers, is free, in English and Italian, and consists of over 500 slides with many movies and animations.

https://www.robertomerletti.it/en/emg/material/teaching/

The challenge

Among the branches of medicine, rehabilitation is probably the one with the strongest interaction with physics and engineering. Rehabilitation sciences involve mechanical, electronic, robotic, material and signal processing engineering.

New professions are evolving and old professions are radically changing under the pressure of novel sensing, processing and visualization techniques. New teaching approaches are required.



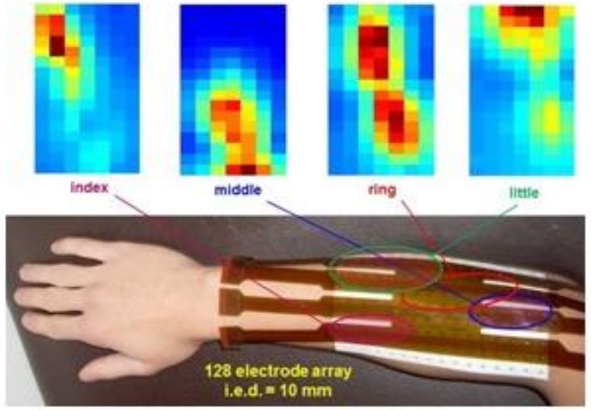
Surface EMG maps associated to eversion and dorsiflexion of the foot. Longitudinal differential detection. Electrode grid of 8x8 contacts. Interelectrode distance = 10mm

Applications

The development of advanced sEMG technology, often combined with inertial measurement units (IMU), has widely extended the applications in a variety of fields ranging from monitoring the effectivness of treatment and interventions, to occupational and rehabilitation medicine, to sport and preventive medicine, to the investigation of pathophysiology of movement control in healthy or elderly subjects and patients.

Visualization of kinematics and electro-physiological variables provides clinicians with powerful tools for the understanding of movement control disorders.

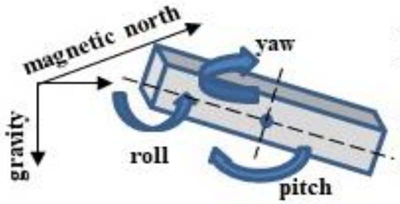
Insight into the technology, limitations, sources of errors and improper use of these tools is a fundamental requirement for rehabilitation operators. In 5-10 years, rehabilitation technology will have strongly impacted on clinical procedures and on their assessment as well as on the activities of operators that are being trained today.



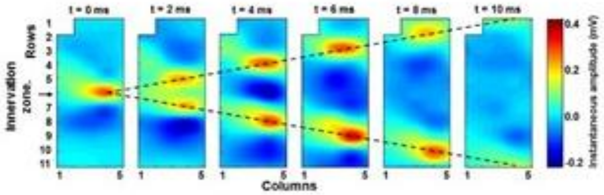
Surface EMG maps associated to the extension of the individual fingers. Longitudinal differential detection. Electrode grid of 16x8 contacts. Interelectrode distance = 10mm.

Decomposition of the sEMG into the constituent motor unit action potential trains is opening up an important window on the control strategies of the CNS. The measurement of spectral features and muscle fiber conduction velocity is providing information on peripheral events.

EMG imaging will likely make available new biofeedback techniques and rehabilitation games will help in recovering lost abilities. The solution of the crosstalk problem will sharpen the monitoring of muscle coordination. These tools will be applicable in preventive, occupational and sport medicine and will provide a more rigorous approach to the assessment of effectiveness of treatments, hopefully reducing social costs or rehabilitation. The training of operators able to use these tools properly should start today.



Inertial Measurement Unit (IMU) to measure bio-mechanical variables.



Propagation of a motor unit action potential under an electrode grid on the biceps brachii. Longitudinal double differential detection. Interelectrode distance = 8 mm.

Bilingual (Italian and English) teaching material freely usable and downloadable from: https://www.robertomerletti.it/en/emg/material/teaching/

Roberto Merletti PhD   Home   EMG   Curriculum Vitae   LISiN

Teaching modules and on-line courses

Movement control and non invasive electromyography: Project CoMES.

- Project CoMES Final report (PDF 1.5 MB)
- Commentaries about Project CoMES (PDF 0.2 MB)
- Introduction (PDF 0.6 MB)
- Module 1 Basic Mechanics
- Module 2 Basic Biomechanics
- Module 3 Basic Electrical Phenomena
- Module 4 Basic Signal Analysis
- Module 5 Basic Electrophysiology and sEMG generation
- Module 6 sEMG Detection Systems
- Module 7 Features and properties of the surface EMG signal
- Module 8 European recommendations and their updating
- Module 9 Modeling of sEMG (in preparation)
- Module 10 Examples of acquisition and interpretation of sEMG signals

The final report and the teaching material resulting from the COMES Project are freely available to anybody under Creative Commons Licence.

Over 500 slides and movies aimed at life scientists, teachers, and clinical operators. Addition of a narrating voice (Italian version) is under way.

Additional teaching material

- Video lectures on Basic Electricity from Prof S. Gupta, G D Goenka University, India (addendum to Module 3)

International Society of Electrophysiology and Kinesiology

First two tutorials for non-engineers. JEK 2019 and 2020.

Journal of Electromyography and Kinesiology 49 (2019) 1023
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Journal of Electromyography and Kine
journal homepage: www.elsevier.com/locate/jele
https://doi.org/10.1016/j.jelekin.2019.102363

Tutorial. Surface EMG detection in space and time: Best pra

R. Merletti[a,*], S. Muceli[b,c]

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[b] Division of Signal Processing and Biomedical Engineering, Department of Electrical Engineering, Chalmers University of Technology,
[c] Imperial College, London, UK

ARTICLE INFO

Keywords:
Tutorial
Teaching
surface EMG
High Density sEMG
Multichannel array sEMG
Physiotherapists
Kinesiologists
Movement scientists

ABSTRACT

This tutorial is aimed to non-engineers using, or planning t
sessment tool in the prevention, monitoring and rehabilitat
related to the origin and nature of the signal and to its de
dimensional (bipolar and linear arrays) and two-dimensional
mathematical, physical or physiological issues. Its second pur
guidelines for proper signal detection. Issues related to the
interpretation will be discussed in subsequent tutorials.

Other tutorials are in preparation.

Journal of Electromyography and Kinesiology 54 (2020) 102440
Contents lists available at ScienceDirect
Journal of Electromyography and Kinesiology
journal homepage: www.elsevier.com/locate/jelekin
https://doi.org/10.1016/j.jelekin.2020.102440

Tutorial. Surface EMG detection, conditioning and pre-processing: Best practices

R. Merletti*, G.L. Cerone

LISiN - Laboratory for Engineering of the Neuromuscular System, Department of Electronics and Telecommunications - Politecnico di Torino, Turin, Italy

ARTICLE INFO

Keywords:
Tutorial
Teaching
Electromyography
sEMG detection
Physiotherapy
Kinesiology
Electrodes
Signal conditioning
sEMG amplifier
Electrode–skin impedance
Interference reduction
Noise reduction
Artifact reduction

ABSTRACT

This tutorial is aimed primarily to non-engineers, using or planning to use surface electromyography (sEMG) as an assessment tool for muscle evaluation in the prevention, monitoring, assessment and rehabilitation fields. The main purpose is to explain basic concepts related to: (a) signal detection (electrodes, electrode–skin interface, noise, ECG and power line interference), (b) basic signal properties, such as amplitude and bandwidth, (c) parameters of the front-end amplifier (input impedance, noise, CMRR, bandwidth, etc.), (d) techniques for interference and artifact reduction, (e) signal filtering, (f) sampling and (g) A/D conversion, These concepts are addressed and discussed, with examples.

The second purpose is to outline best practices and provide general guidelines for proper signal detection, conditioning and A/D conversion, aimed to clinical operators and biomedical engineers. Issues related to the sEMG origin and to electrode size, interelectrode distance and location, have been discussed in a previous tutorial. Issues related to signal processing for information extraction will be discussed in a subsequent tutorial.

International Society of Electrophysiology and Kinesiology

Consensus for Experimental Design in Electromyography (CEDE).

Journal of Electromyography and Kinesiology 48 (2019) 128–144

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

ELSEVIER

Consensus for experimental design in electromyography (CEDE) project: Electrode selection matrix

Manuela Besomi[a], Paul W. Hodges[a,*], Jaap Van Dieën[b], Richard G. Carson[c,d,e], Edward A. Clancy[f], Catherine Disselhorst-Klug[g], Aleš Holobar[h], François Hug[a,i,j], Matthew C. Kiernan[k,l], Madeleine Lowery[m], Kevin McGill[n], Roberto Merletti[o], Eric Perreault[p,q], Karen Søgaard[r], Kylie Tucker[a,s], Thor Besier[t], Roger Enoka[u], Deborah Falla[v], Dario Farina[w], Simon Gandevia[x], John C. Rothwell[y], Bill Vicenzino[a], Tim Wrigley[z]

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[j] Institut Universitaire de France (IUF), Paris, France
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Journal of Electromyography and Kinesiology 53 (2020) 102438

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

ELSEVIER

Consensus for experimental design in electromyography (CEDE) project: Amplitude normalization matrix

Check for updates

Manuela Besomi[a], Paul W. Hodges[a,*], Edward A. Clancy[b], Jaap Van Dieën[c], François Hug[a,d,e], Madeleine Lowery[f], Roberto Merletti[g], Karen Søgaard[h], Tim Wrigley[i], Thor Besier[j], Richard G. Carson[k,l,m], Catherine Disselhorst-Klug[n], Roger M. Enoka[o], Deborah Falla[p], Dario Farina[q], Simon Gandevia[r], Aleš Holobar[s], Matthew C. Kiernan[t,u], Kevin McGill[v], Eric Perreault[w,x], John C. Rothwell[y], Kylie Tucker[a,z]

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[y] Sobell Department of Motor Neuroscience and Movement Disorders, UCL Institute of Neurology, London, UK
[z] School of Biomedical Sciences, The University of Queensland, Brisbane, Australia

Four other CEDE papers are accepted or in preparation.

International Society of
Electrophysiology and Kinesiology

Fontiers Editorial Project and Open e-Book:

“Surface Electromyography:
Barriers limiting widespread use of sEMG in clinical assessment and neurorehabilitation.”

The book, as well as the individual contributions, are freely available from:

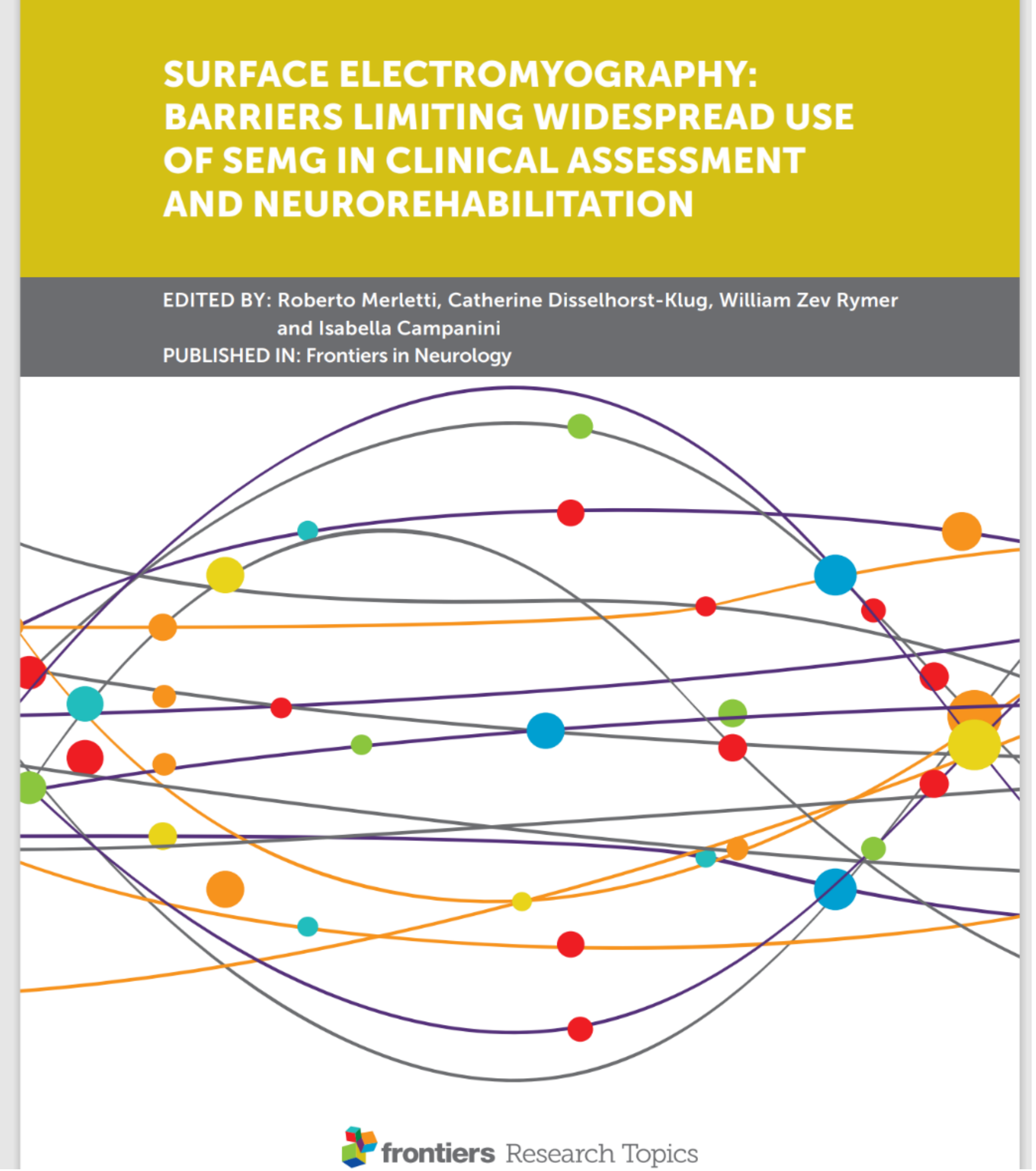
https://www.frontiersin.org/research-topics/11157

18 contributions from 80 authors.

More than 45000 individual visitors and 8000 downloads worldwide (July 10 2021) from many countries:

USA: 8600 views
China: 6000 views
Italy: 3700 views
Germany: 2200 views
Ireland: 1500 views
and many others.

Thank you for your attention



International Society of
Electrophysiology and Kinesiology

CHALMERS
UNIVERSITY OF TECHNOLOGY

Surface EMG detection in space and time
Best practices

Silvia Muceli
muceli@chalmers.se

Chalmers University of Technology
Gothenburg, Sweden

Roberto Merletti, Giacinto Luigi Cerone, Tiffany Hamstreet

Tutorial. Surface EMG detection in space and time: Best practices - ScienceDirect

Journal of Electromyography and Kinesiology 49 (2019) 102363

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journal homepage: www.elsevier.com/locate/jelekin

ELSEVIER

Tutorial. Surface EMG detection in space and time: Best practices

R. Merletti[a,*], S. Muceli[b,c]

[a] LISiN, Dept. of Electronics and Telecommunications, Politecnico di Torino, Italy
[b] Division of Signal Processing and Biomedical Engineering, Department of Electrical Engineering, Chalmers University of Technology, Gothenburg, Sweden
[c] Imperial College, London, UK

A R T I C L E I N F O

Keywords:
Tutorial
Teaching
surface EMG
High Density sEMG
Multichannel array sEMG
Physiotherapists
Kinesiologists
Movement scientists

A B S T R A C T

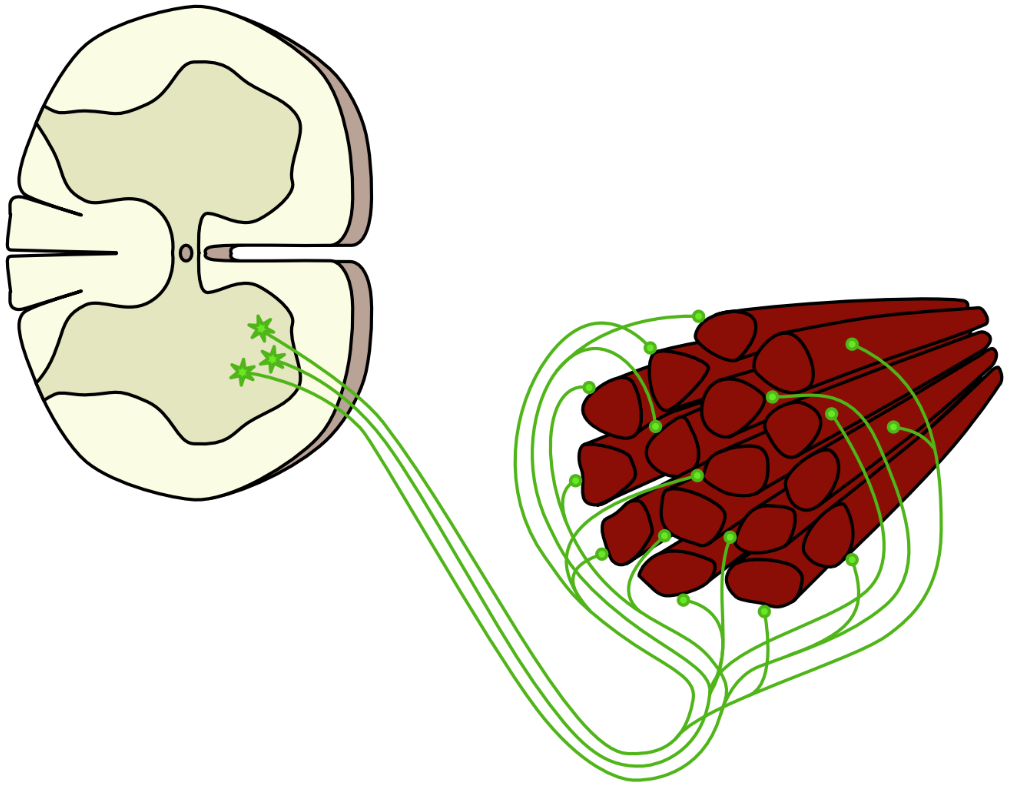
This tutorial is aimed to non-engineers using, or planning to use, surface electromyography (sEMG) as an assessment tool in the prevention, monitoring and rehabilitation fields. Its first purpose is to address the issues related to the origin and nature of the signal and to its detection (electrode size, distance, location) by one-dimensional (bipolar and linear arrays) and two-dimensional (grids) electrode systems while avoiding advanced mathematical, physical or physiological issues. Its second purpose is to outline best practices and provide general guidelines for proper signal detection. Issues related to the electrode-skin interface, signal conditioning and interpretation will be discussed in subsequent tutorials.

https://doi.org/10.1016/j.jelekin.2019.102363 (open access)

Outline

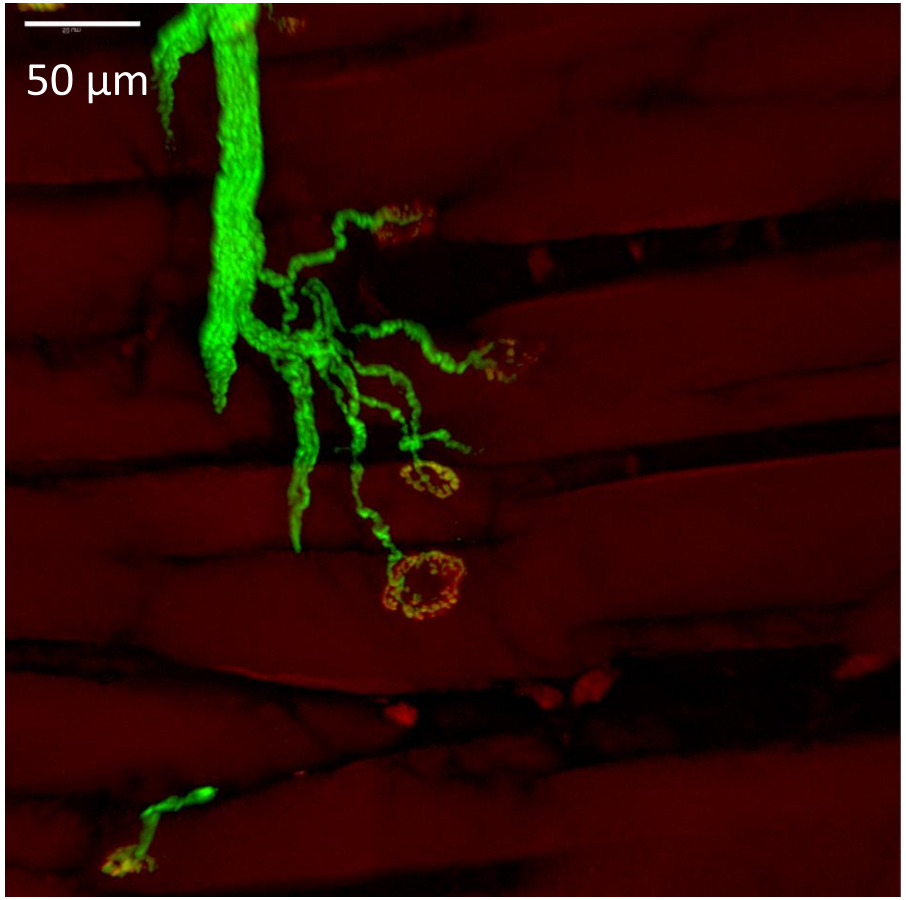
- EMG signal generation
- Propagation in time and space
- Detection systems
- The EMG image
- Electrode size
- Electrode configuration
- Electrode position
- Crosstalk
- Best practice

Motor unit



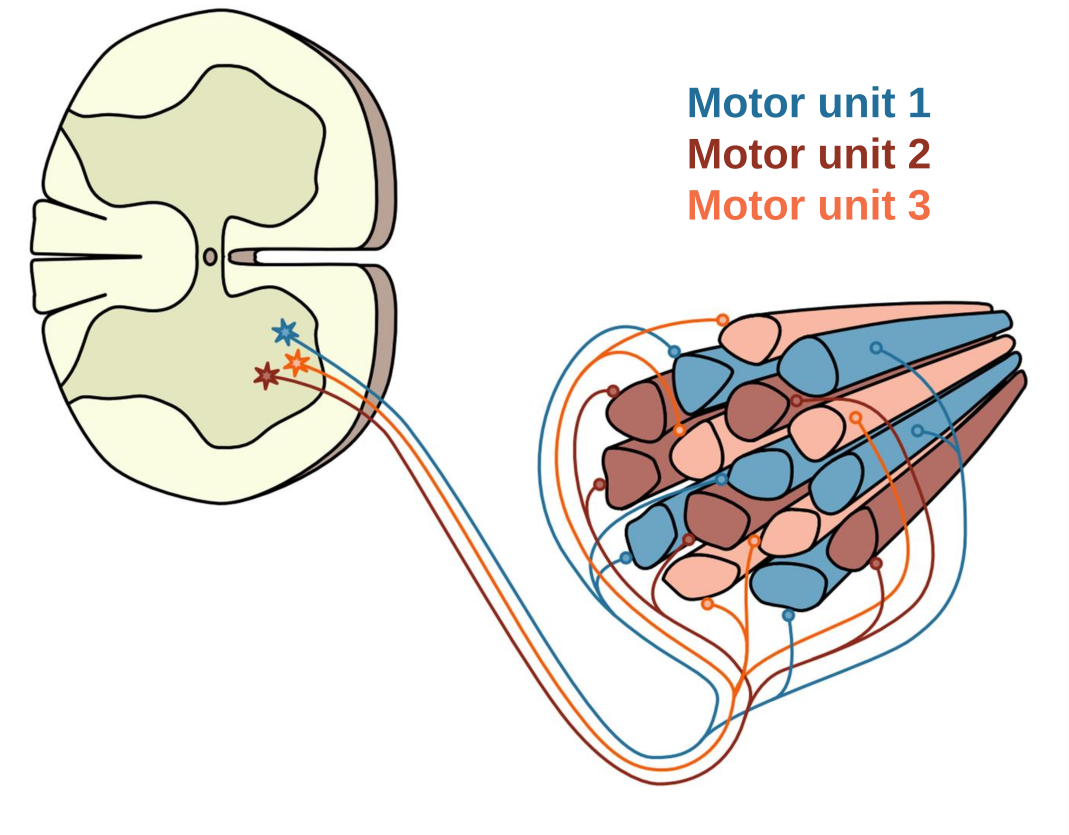
Hamstreet & Muceli, submitted

Neuromuscular junction (NMJ)



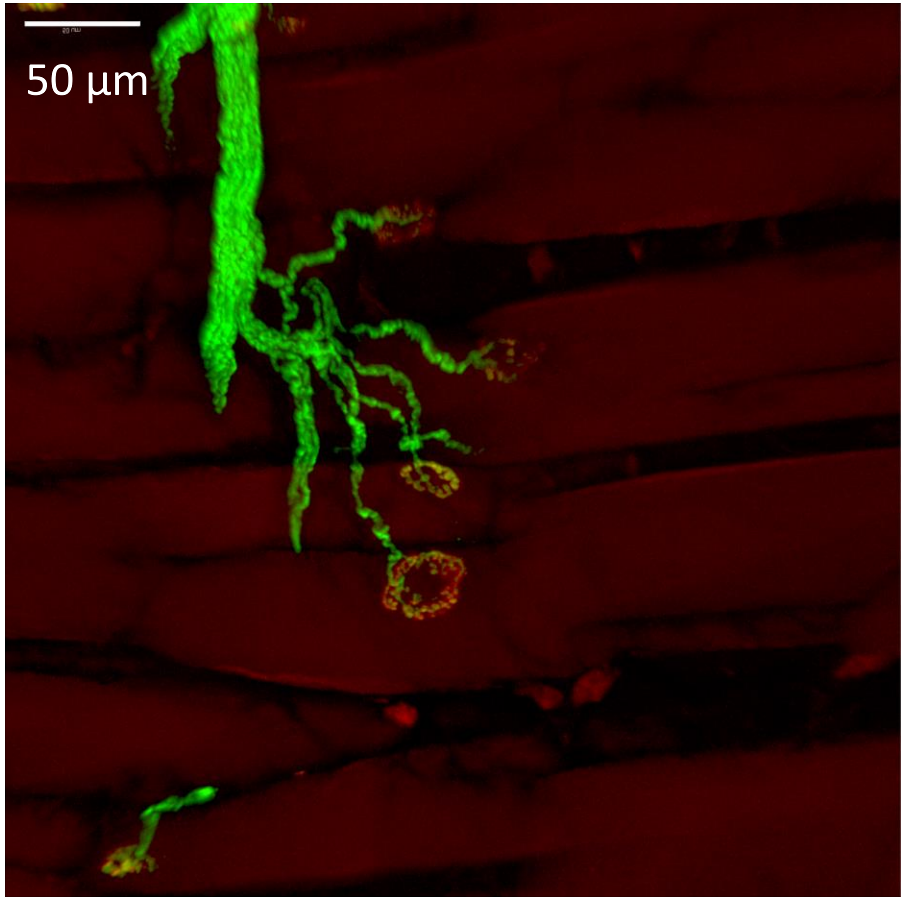
Muceli et al, J Neural Eng, 2019

Motor unit



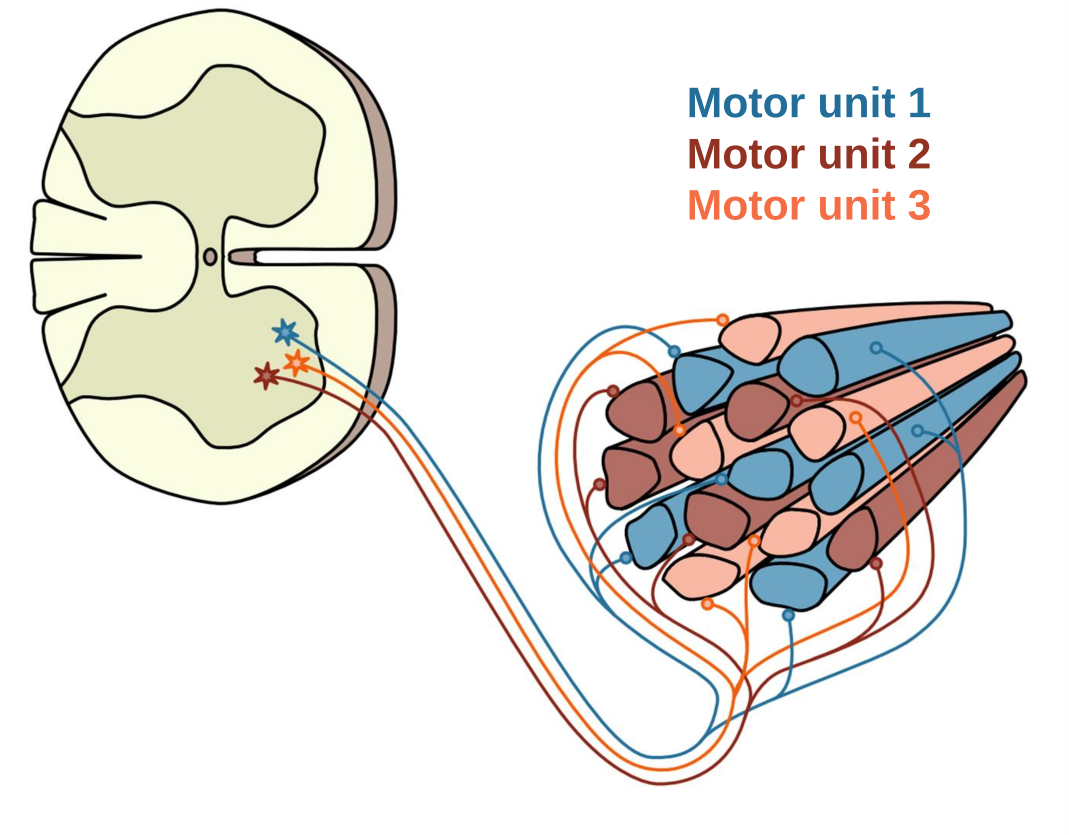
Hamstreet & Muceli, submitted

Neuromuscular junction (NMJ)



Muceli et al, J Neural Eng, 2019

Motor unit

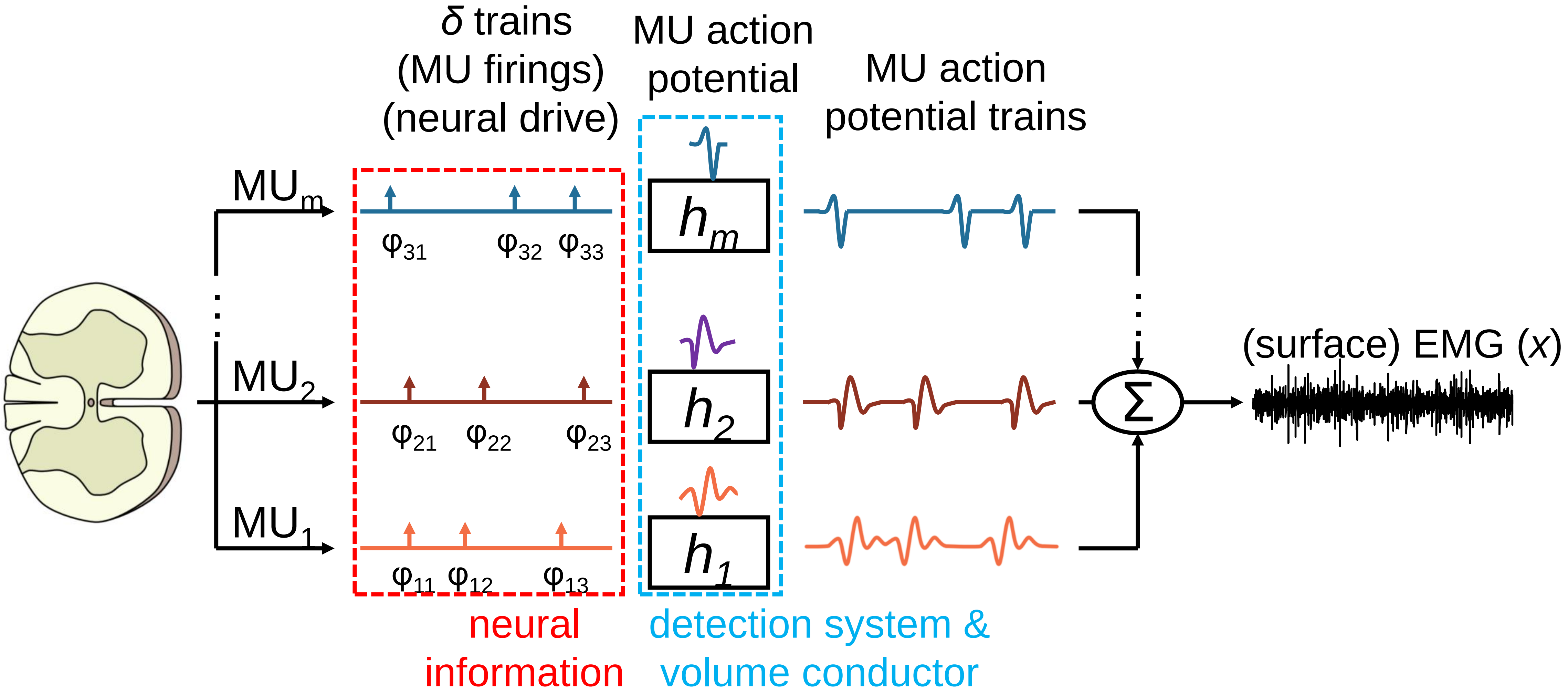


Hamstreet & Muceli, submitted

Muscle	α motor axons	Number of muscle fibers
Biceps brachii[a,c]	774	580,000
Brachioradialis[e]	315	>129,200
	350	
Cricothyroid[a,d]	112	18,550
First dorsal interosseus[e]	119	40,500
First lumbrical[e]	93	10,038
	98	10,500
Opponens pollicis[a,c]	133	79,000
Masseter[b]	1,452	929,000
Platysma[e]	1,096	27,100
Temporalis[b]	1,331	1,247,000
Medial gastrocnemius[e]	579	1,120,000
		964,000
Posterior cricoarytenoid[a,d]	140	16,200
Rectus lateralis[f]	4,150	22,000
Tensor tympani[f]	146	1,100
Tibialis anterior[e]	445	250,200
		292,500
Transverse arytenoid[a,d]	139	34,470

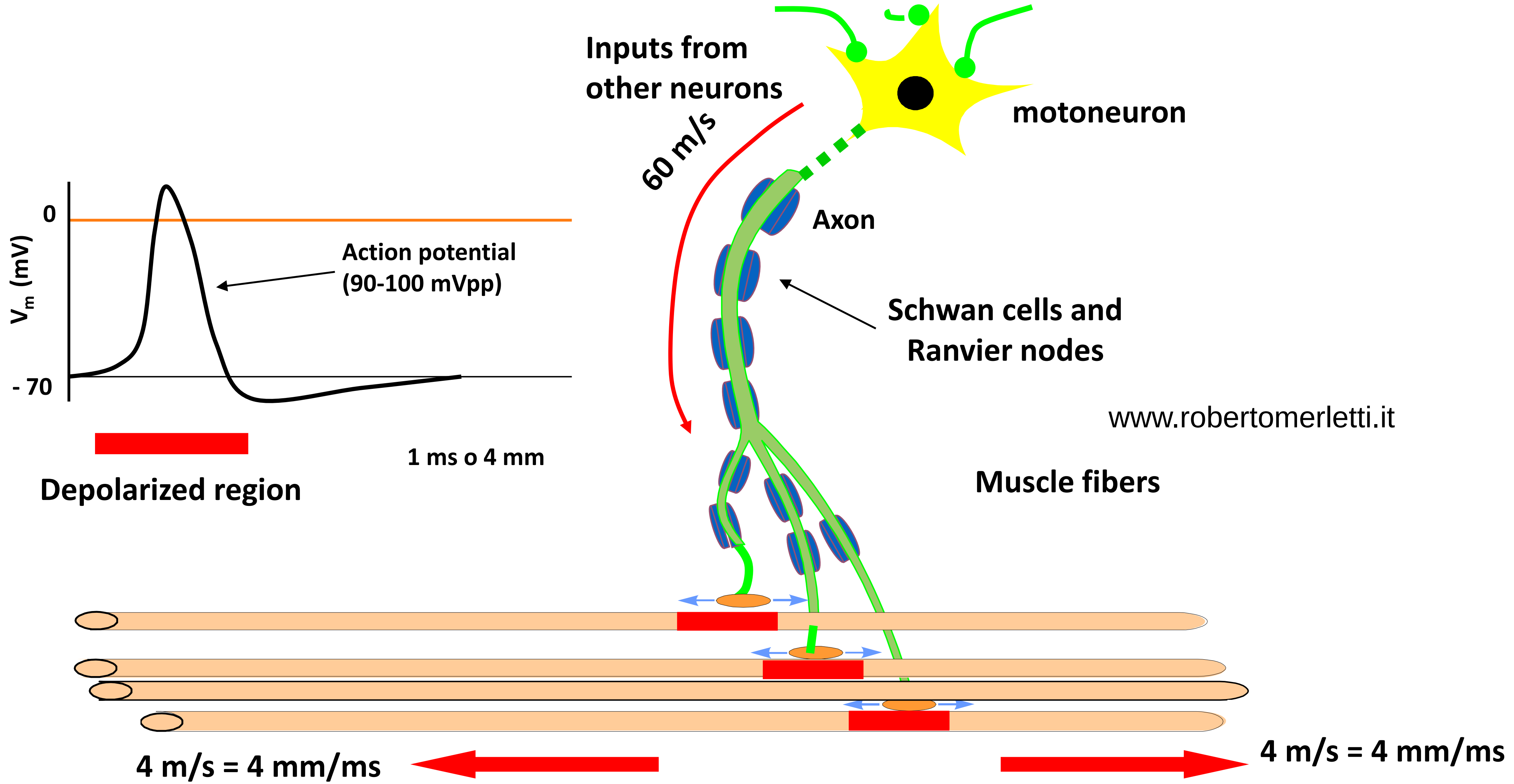
Enoka, J Clin Neurophysiol, 1995

Surface EMG generation



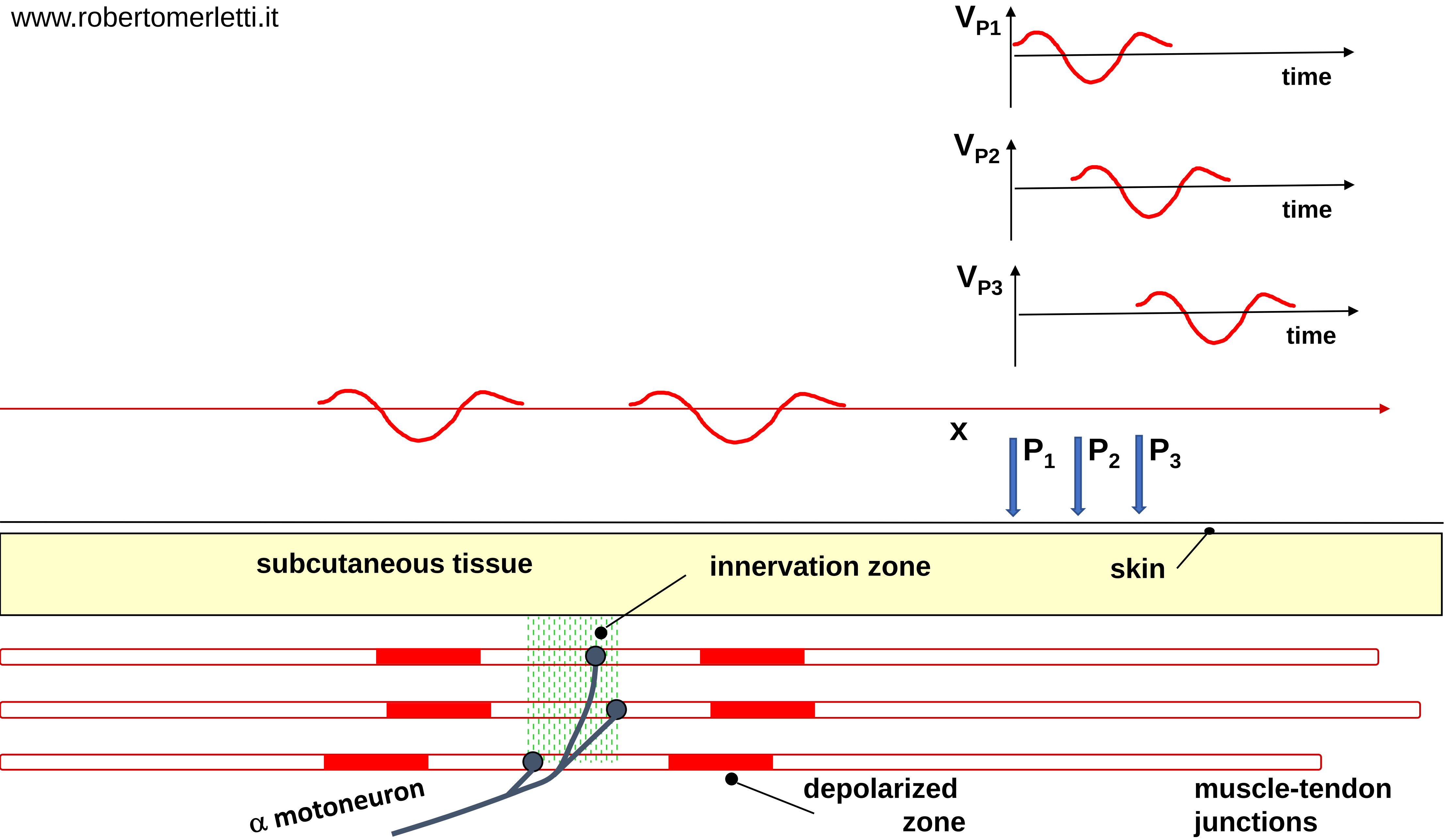
Muceli & Farina, Handbook of Neuroengineering, 2021

Motor unit electrical activity



Propagation in time and space

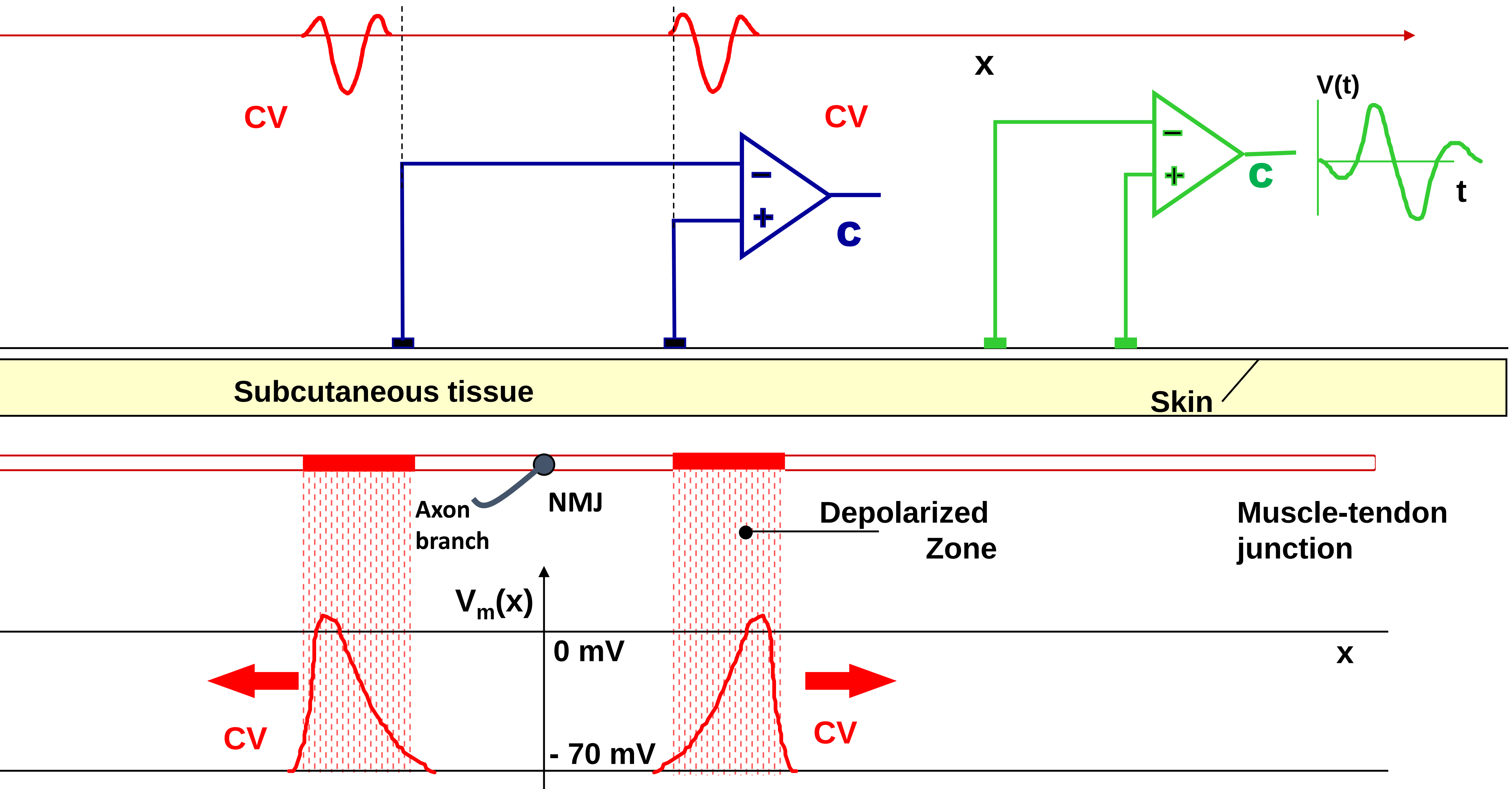
www.robertomerletti.it



Innervation zone

www.robertomerletti.it

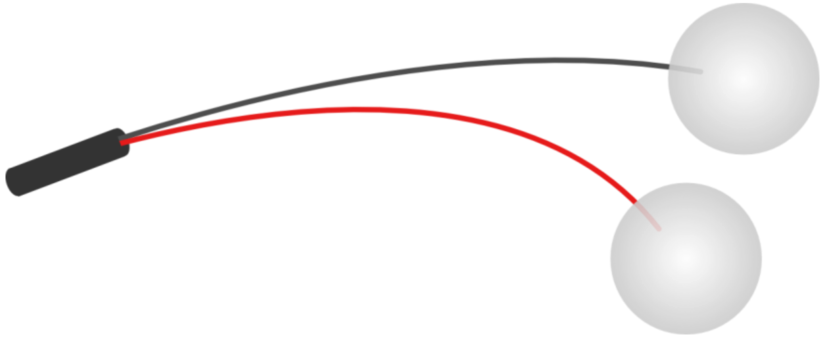
Electrode position matters!



Action potentials travelling towards the tendons

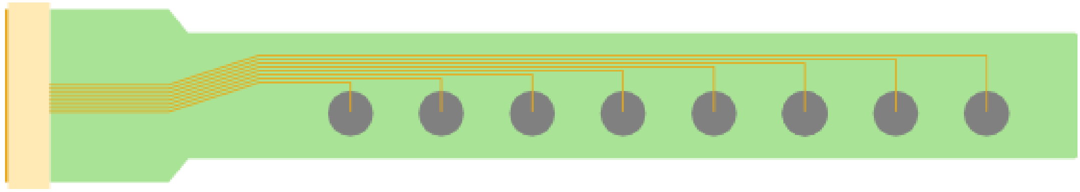
Detection systems

Bipolar electrodes



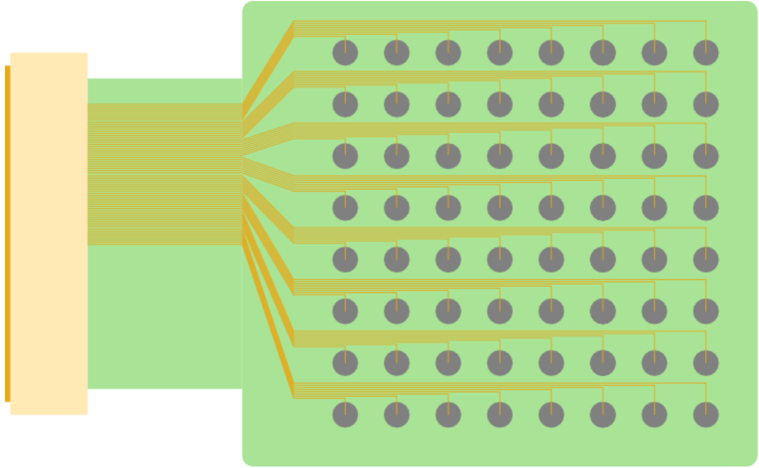
- sEMG timing
- Envelope
- Amplitude
- Spectral variables

Electrode array



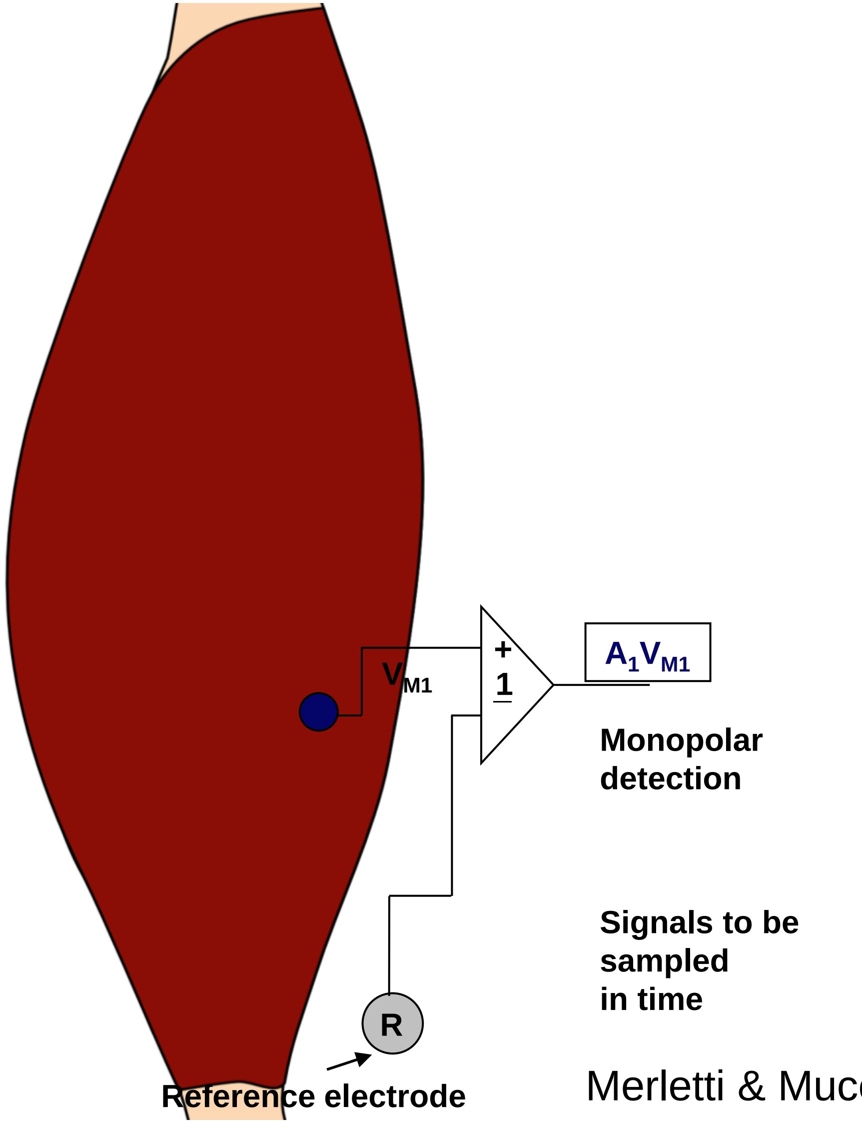
- Optimal electrode position
- Innervation zone
- Fiber length

Electrode grid



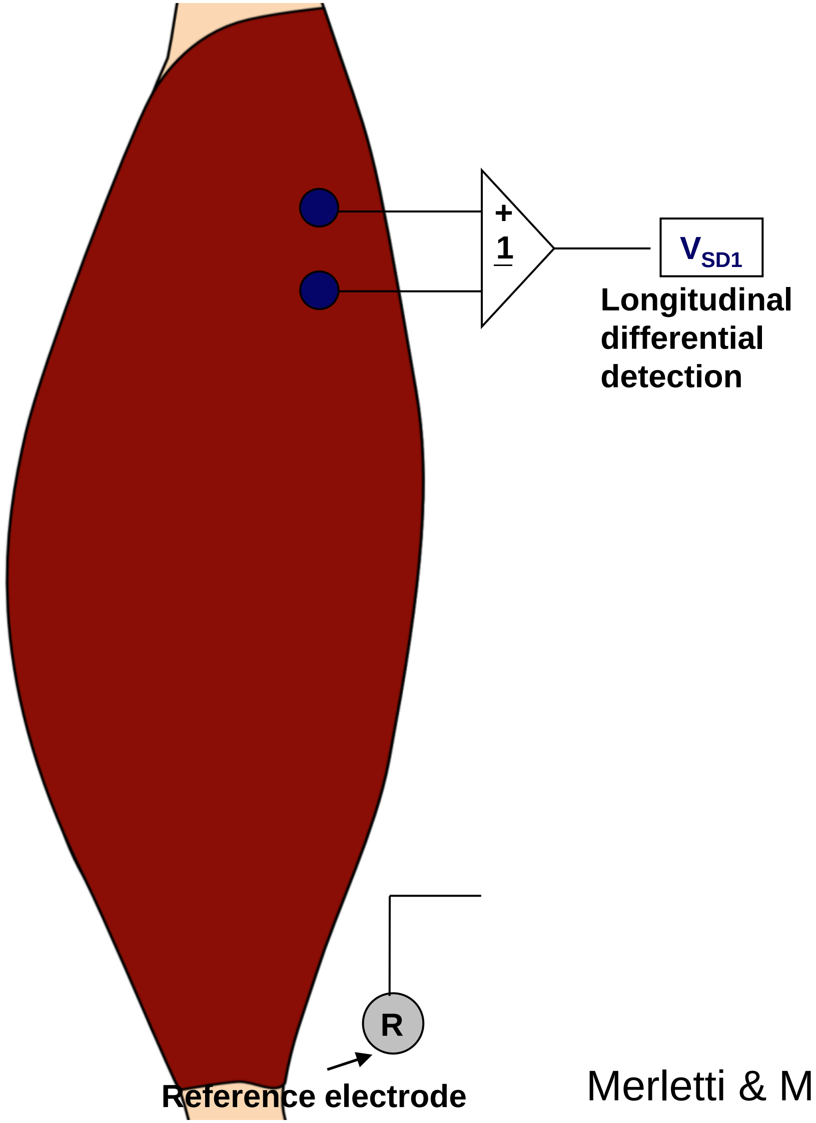
- EMG map
- Active regions
- Centroid

Sampling in time and space



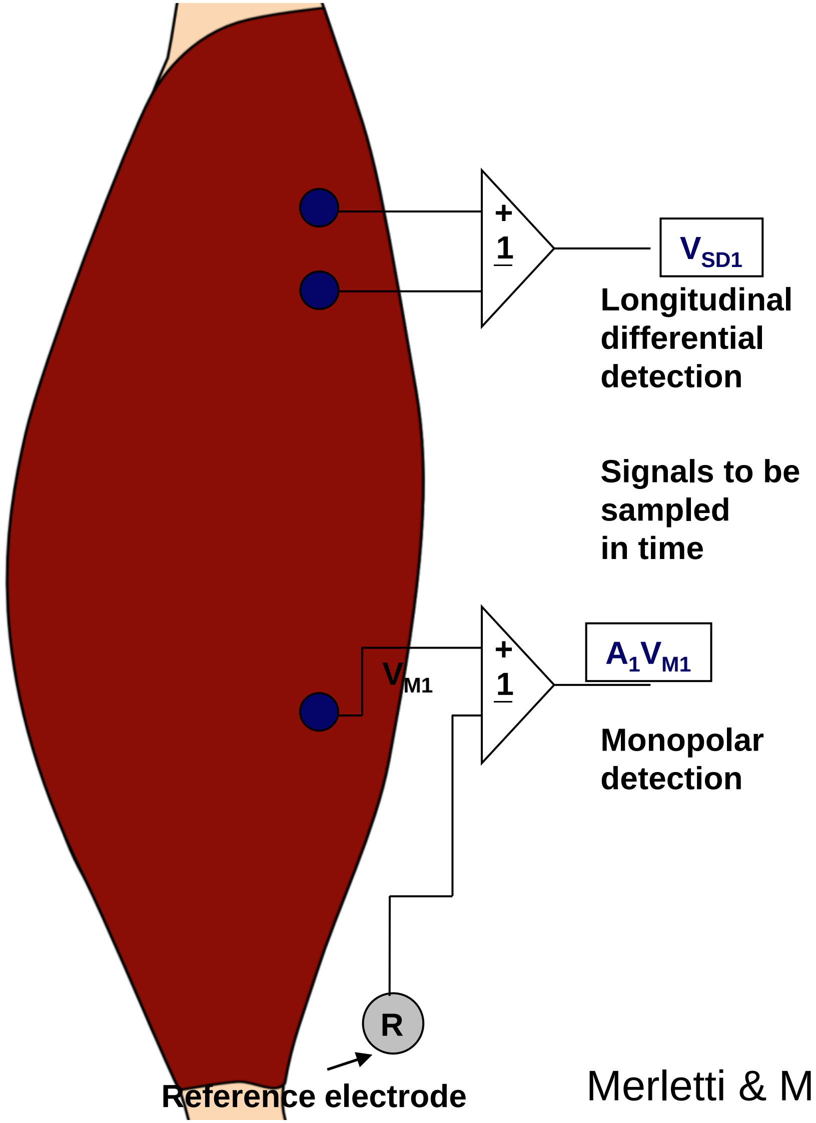
Merletti & Muceli, JEK Tutorial, Fig. 10

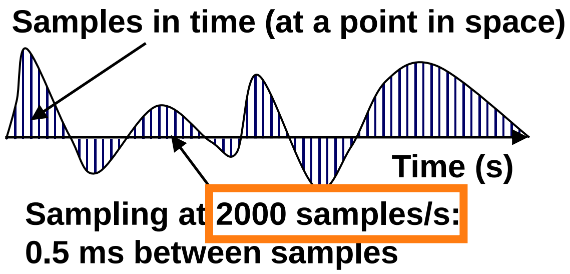
Sampling in time and space



Merletti & Muceli, JEK Tutorial, Fig. 10

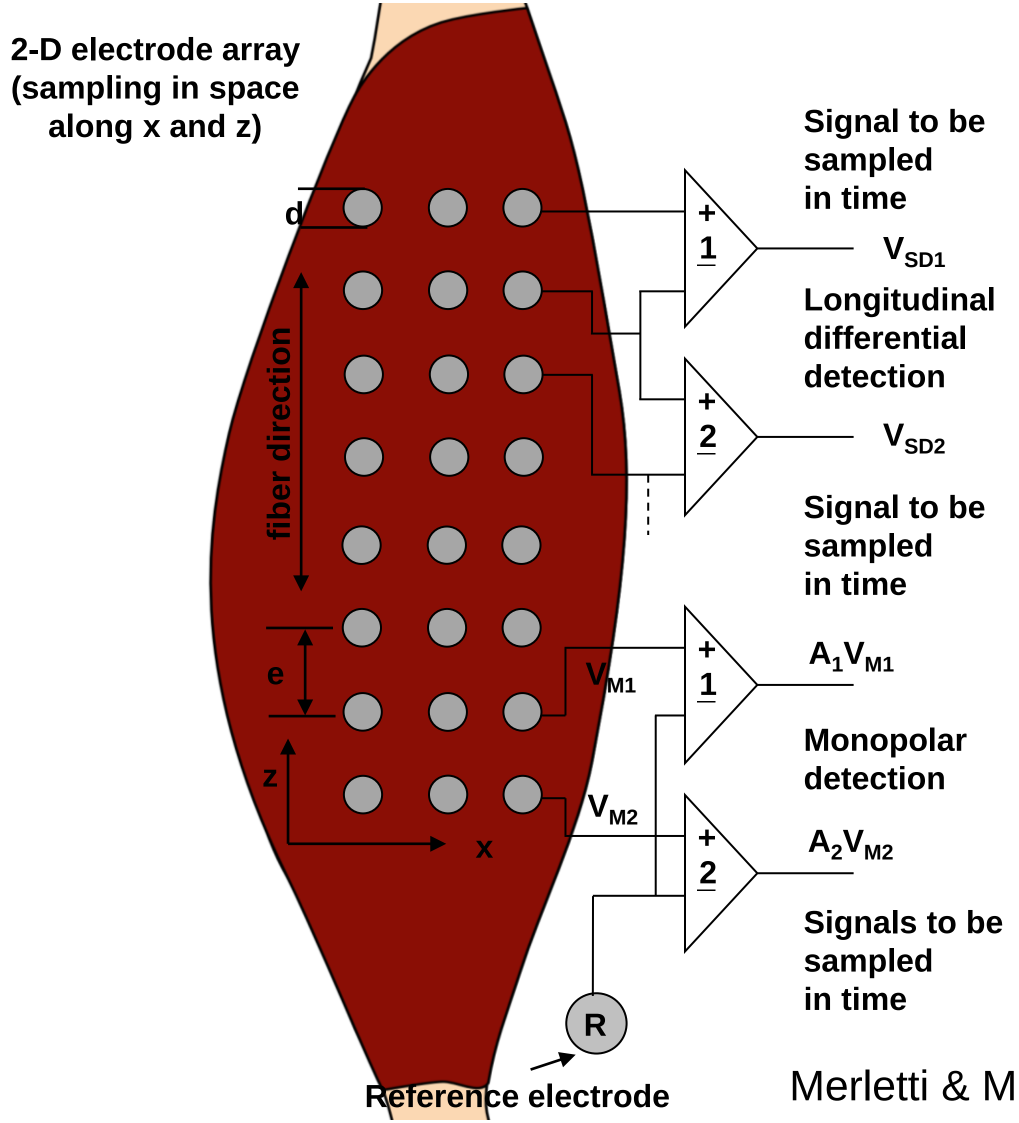
Sampling in time and space

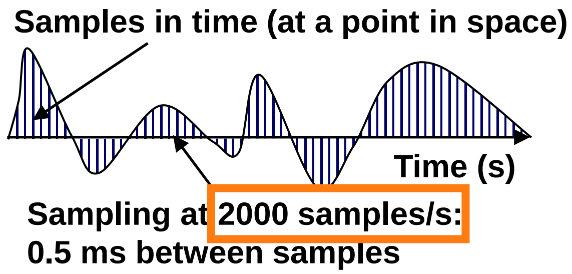




Merletti & Muceli, JEK Tutorial, Fig. 10

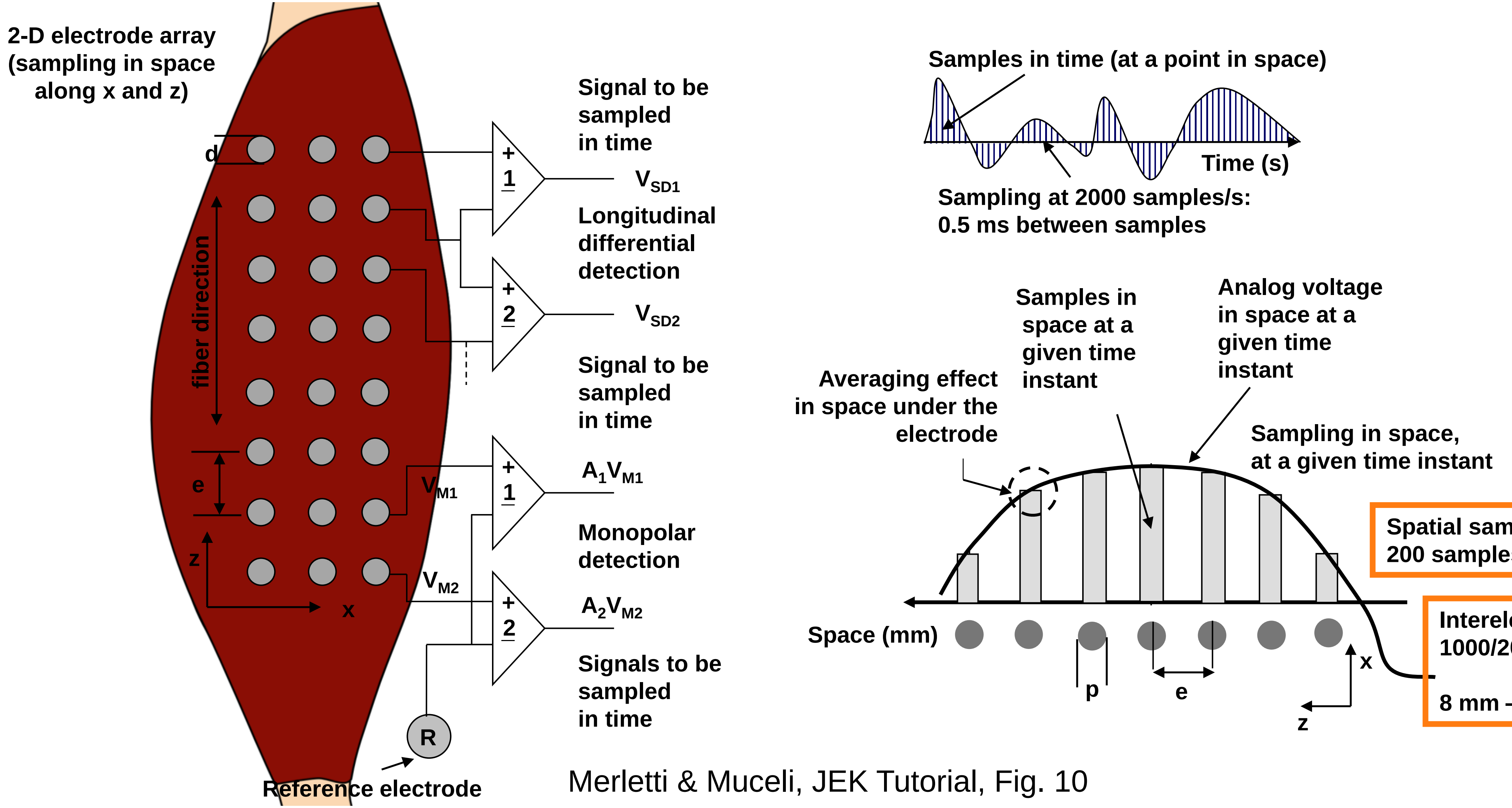
Sampling in time and space





Merletti & Muceli, JEK Tutorial, Fig. 10

Sampling in time and space



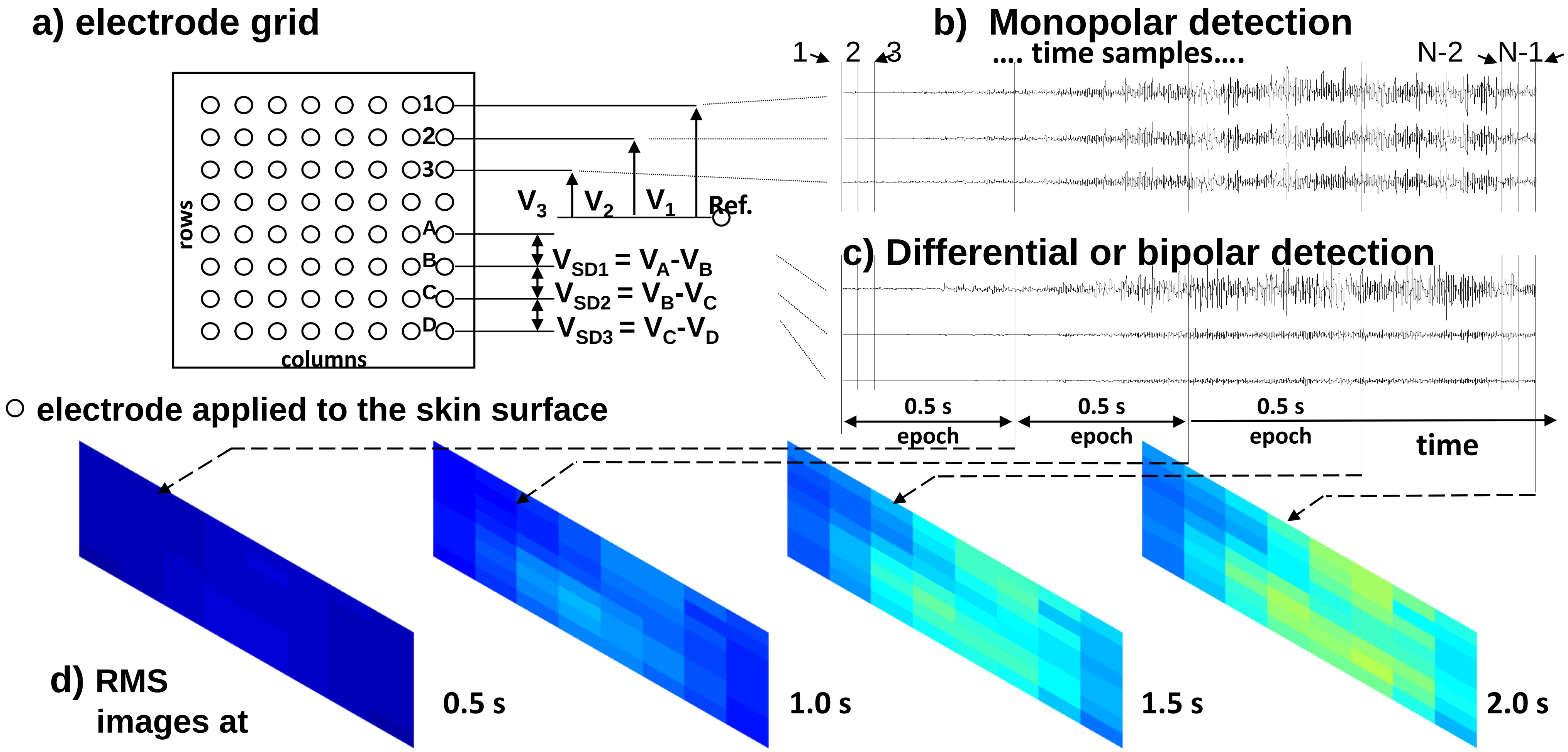
Spatial sampling frequency 200 samples/m

Interelectrode distance 1000/200 mm = 5 mm

8 mm – 10 mm in practice

Merletti & Muceli, JEK Tutorial, Fig. 10

The EMG image

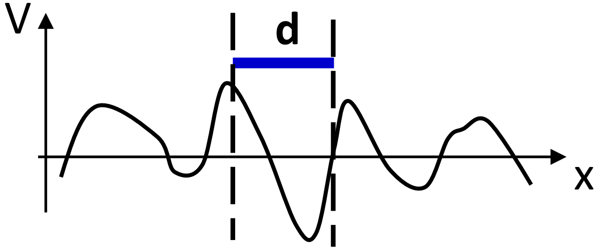


Merletti & Muceli, JEK Tutorial, Fig. 1

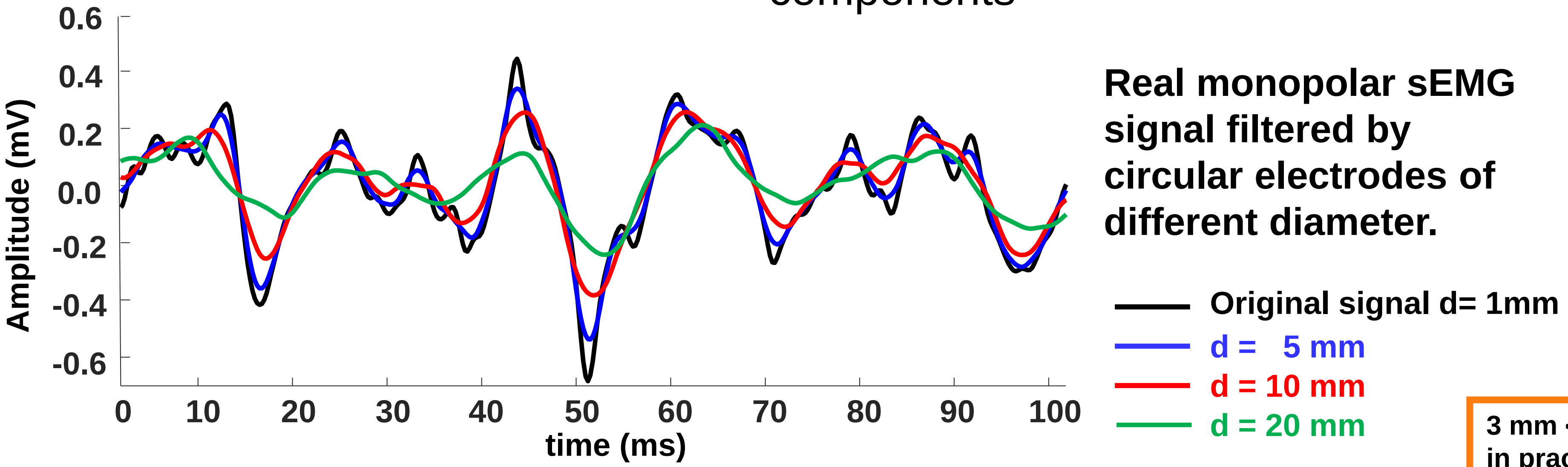
EMG features

- Electrode size
- Electrode configuration
- Electrode position

Electrode size



- Potential: average of the potential on the surface under the electrode
- Average = low-pass filter
- Large electrode reduce high-frequency components

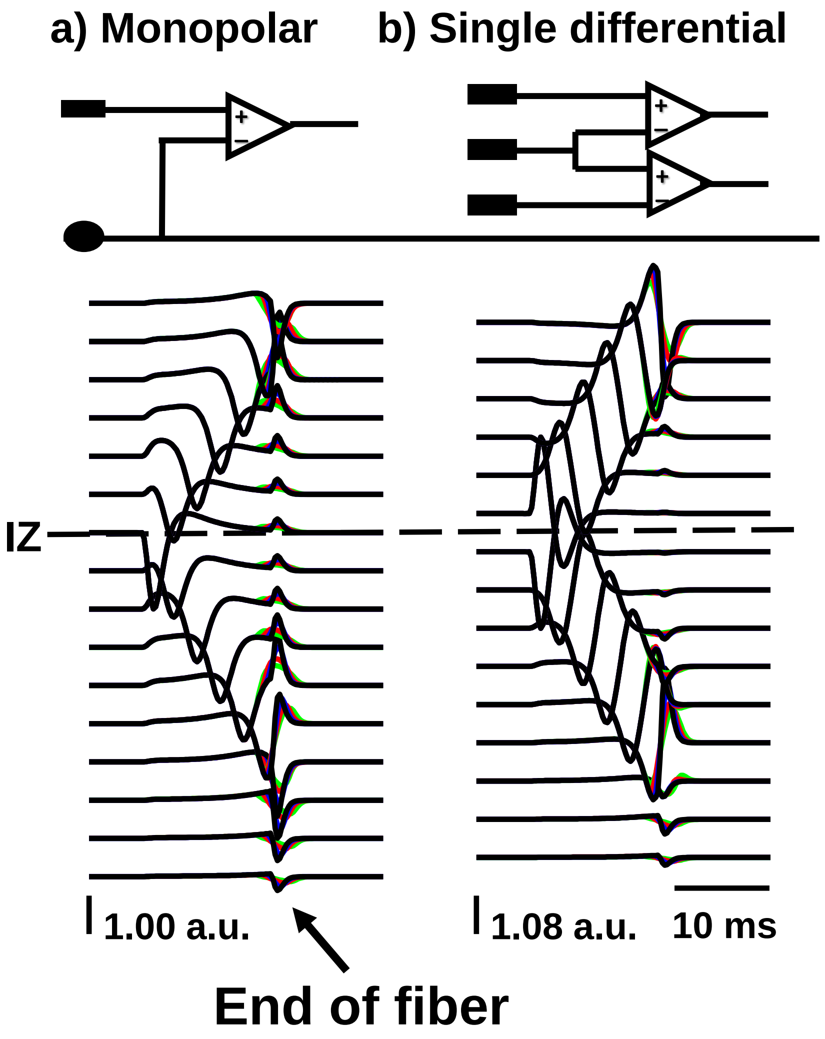


Real monopolar sEMG signal filtered by circular electrodes of different diameter.

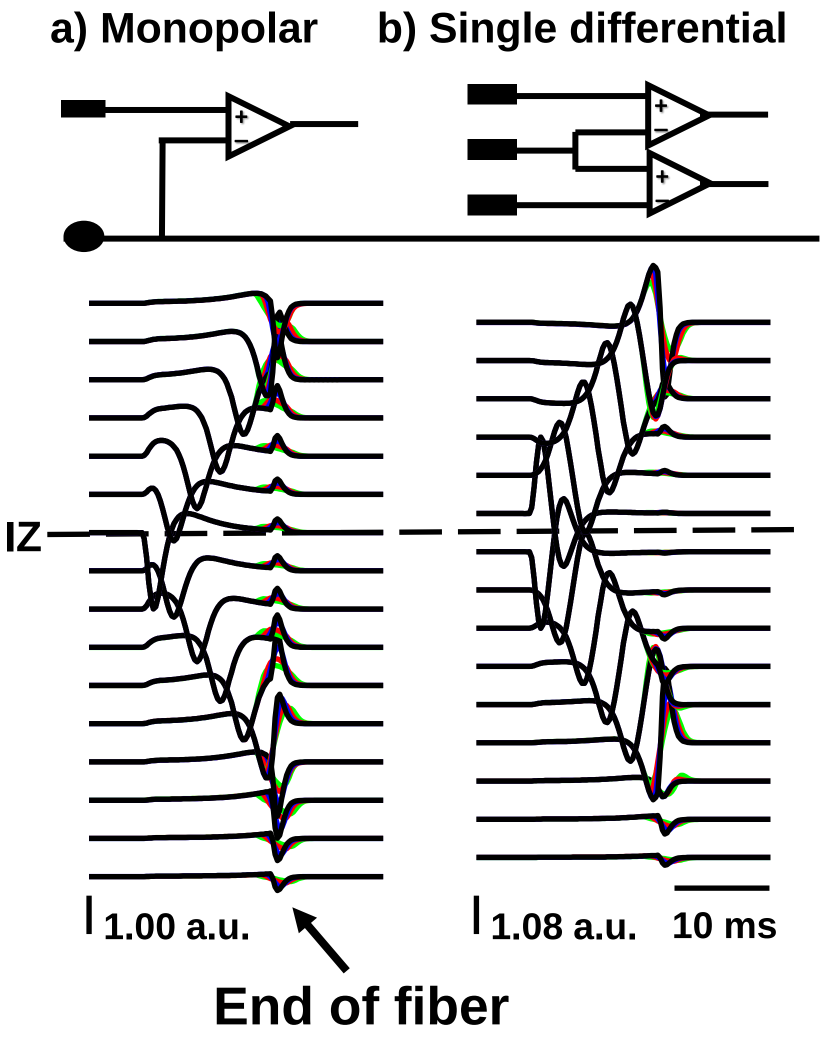
3 mm < d < 5 mm in practice

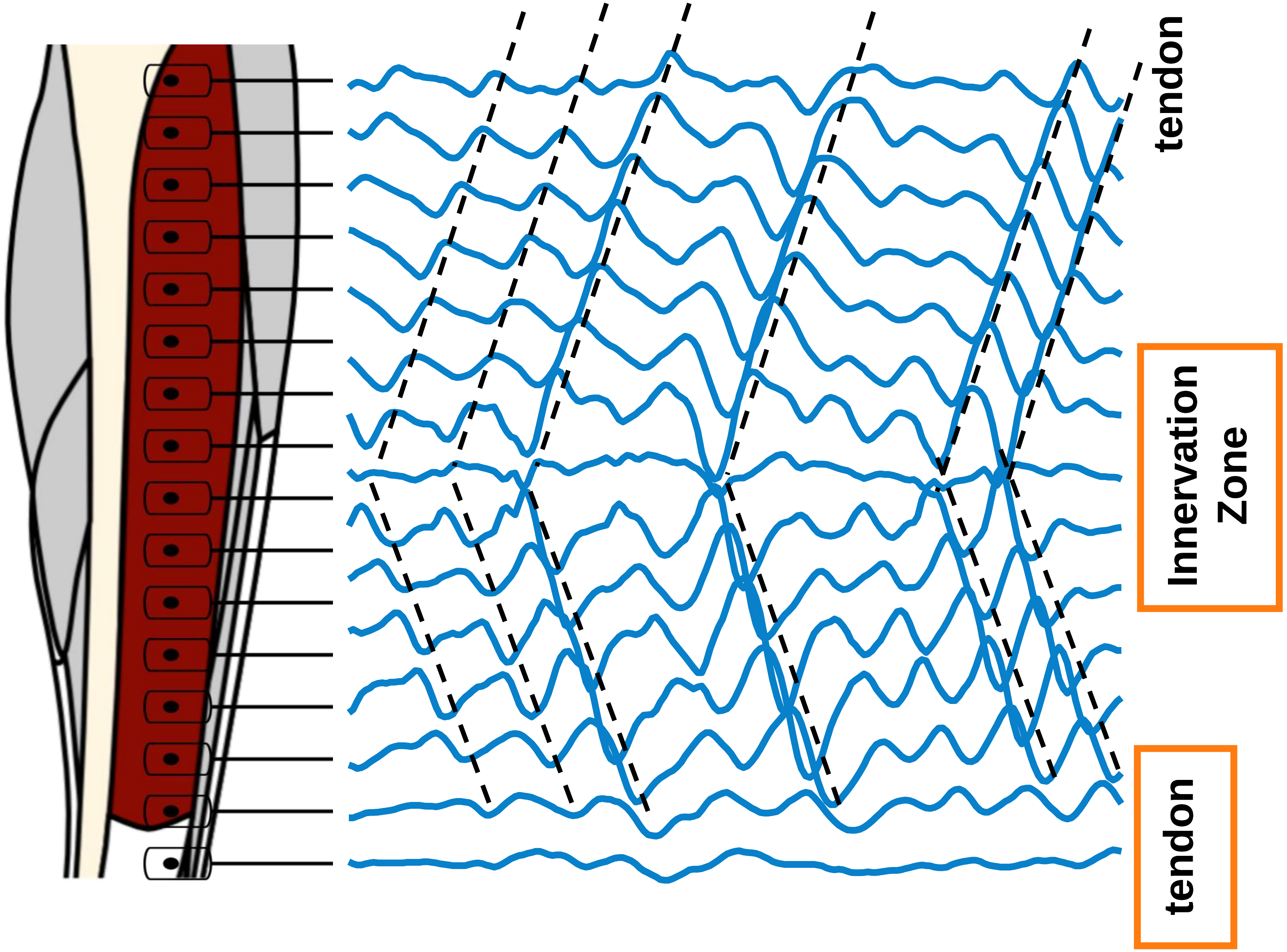
see Merletti & Muceli, JEK Tutorial, Fig. 12

Electrode configuration

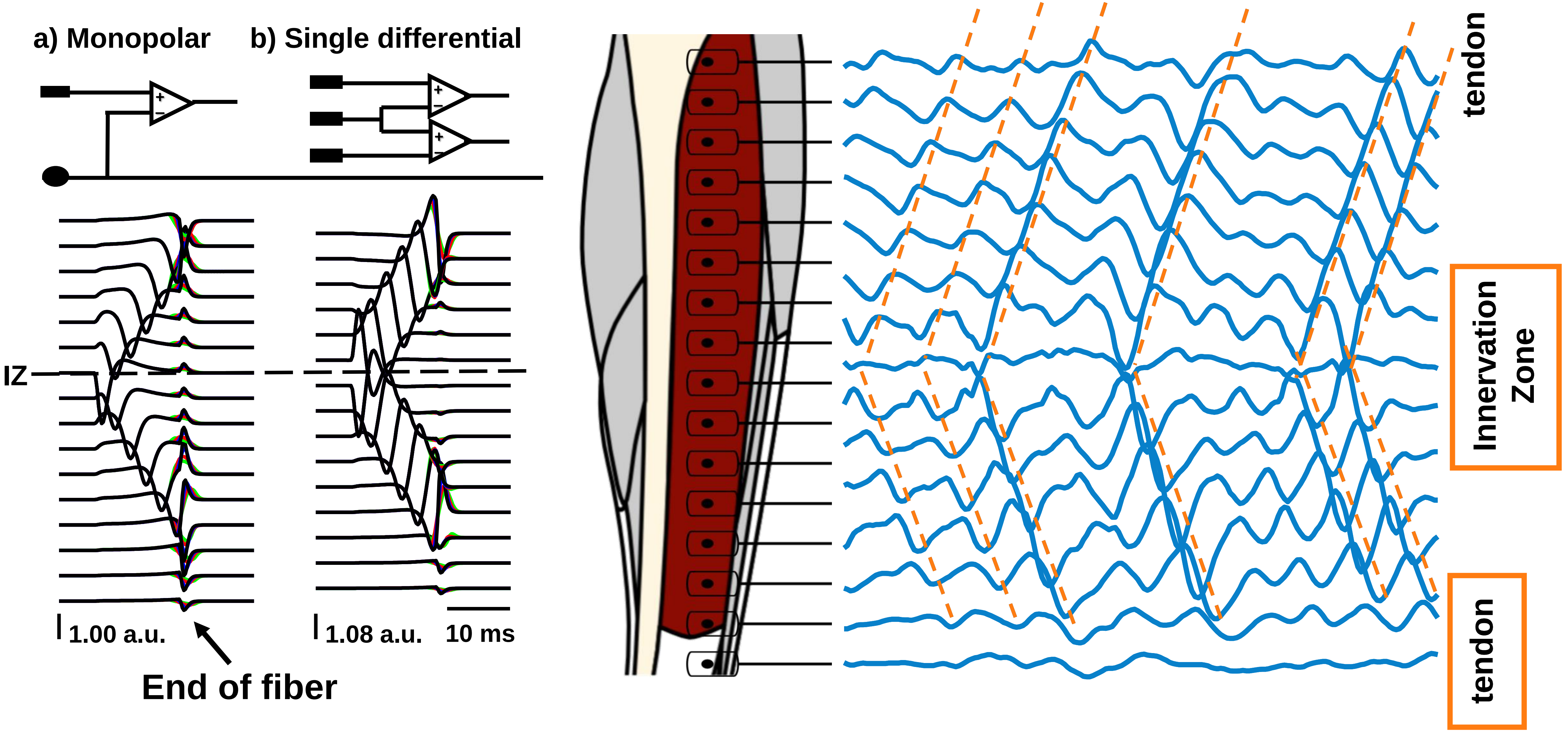


Electrode configuration

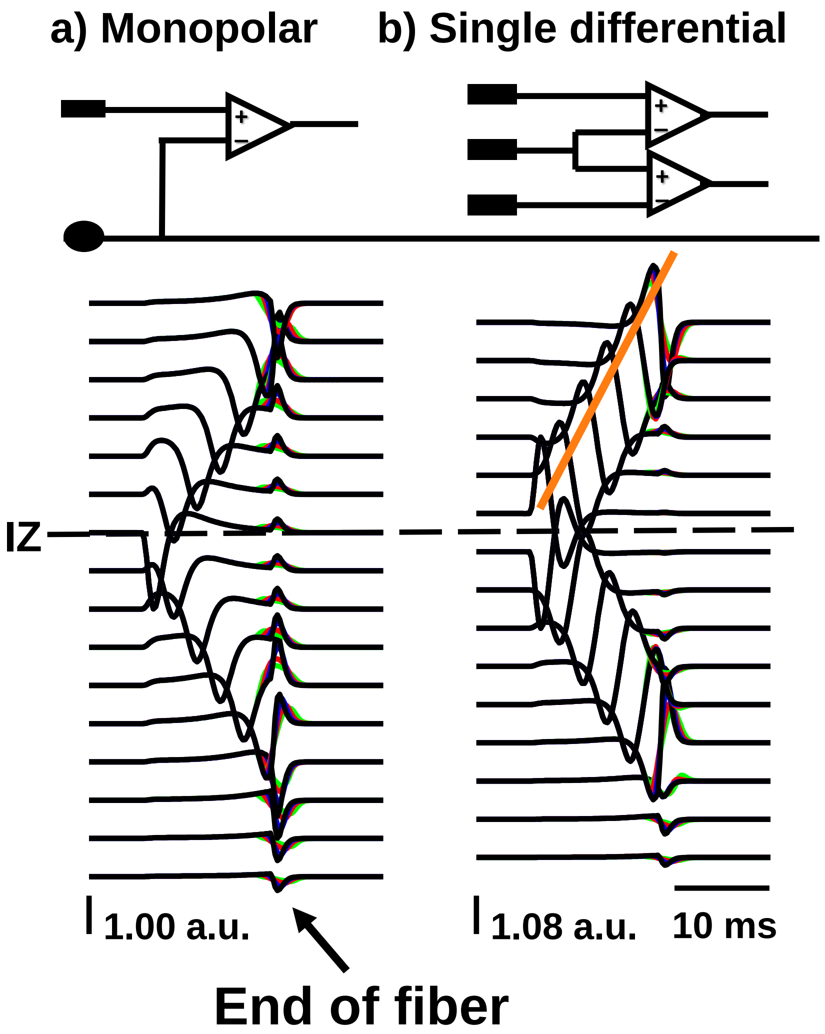




Electrode configuration

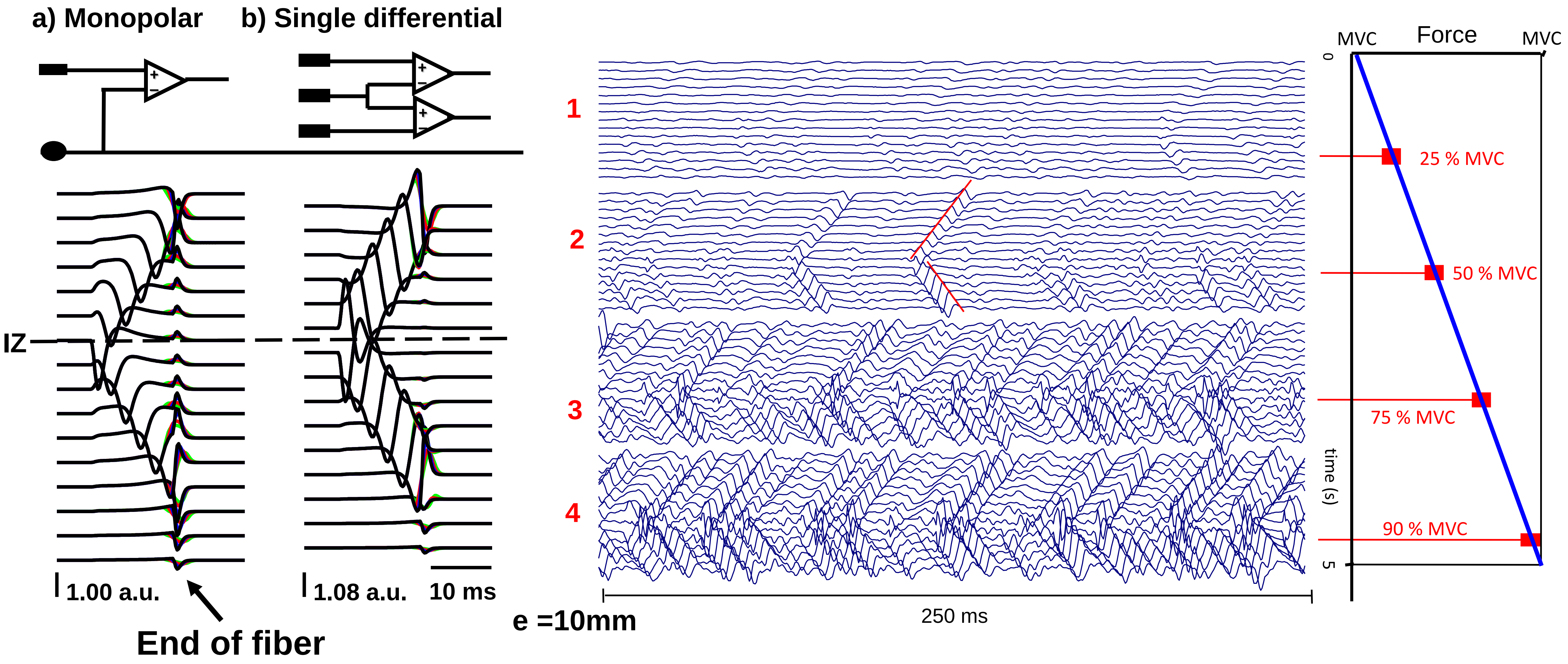


Electrode configuration

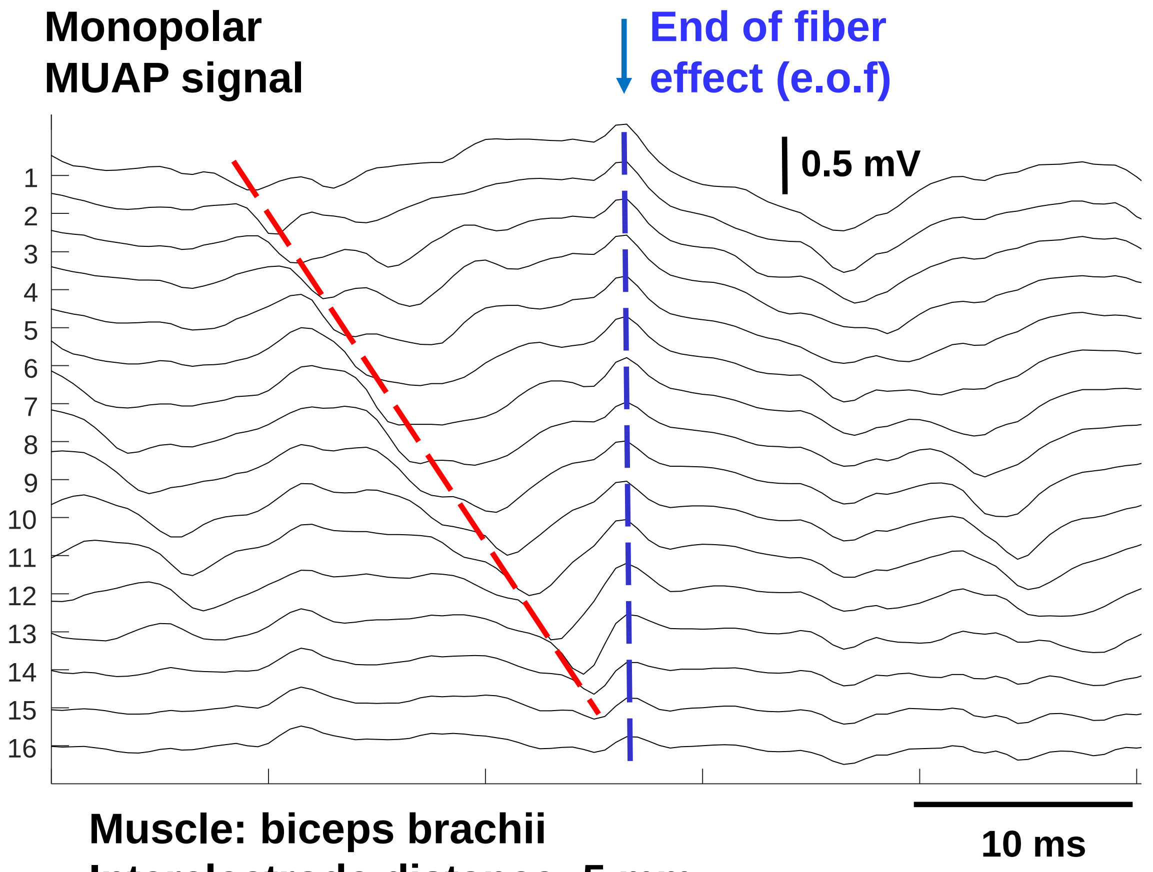


- **Applications (Single differential)**
- Correct positioning of bipolar electrodes between the IZ and the tendon junction
- Conduction velocity estimation
- Targeted injection of botulinum toxin
- Programming surgery to avoid damage to muscle innervation

Electrode configuration

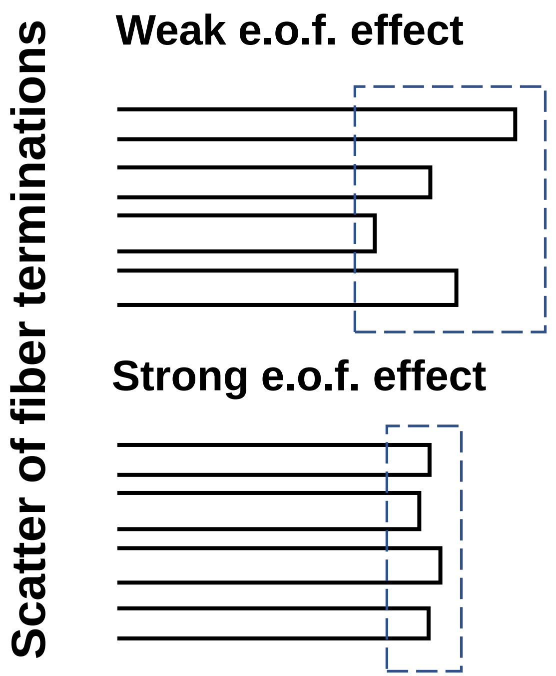


End of fiber effect



Muscle: biceps brachii
Interelectrode distance: 5 mm

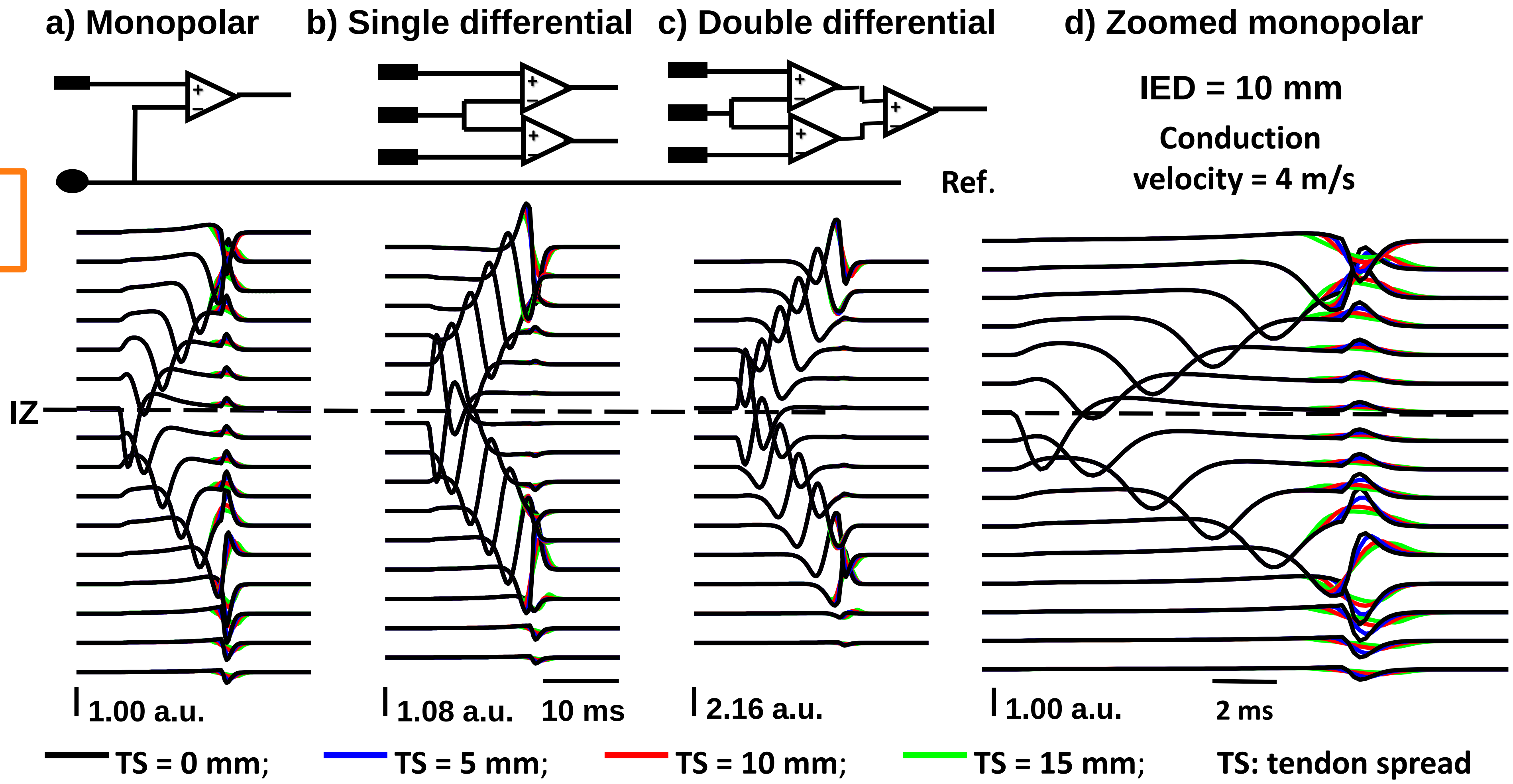
The amplitude of the e.o.f components depends on the spread of the fiber terminations.



www.robertomerletti.it

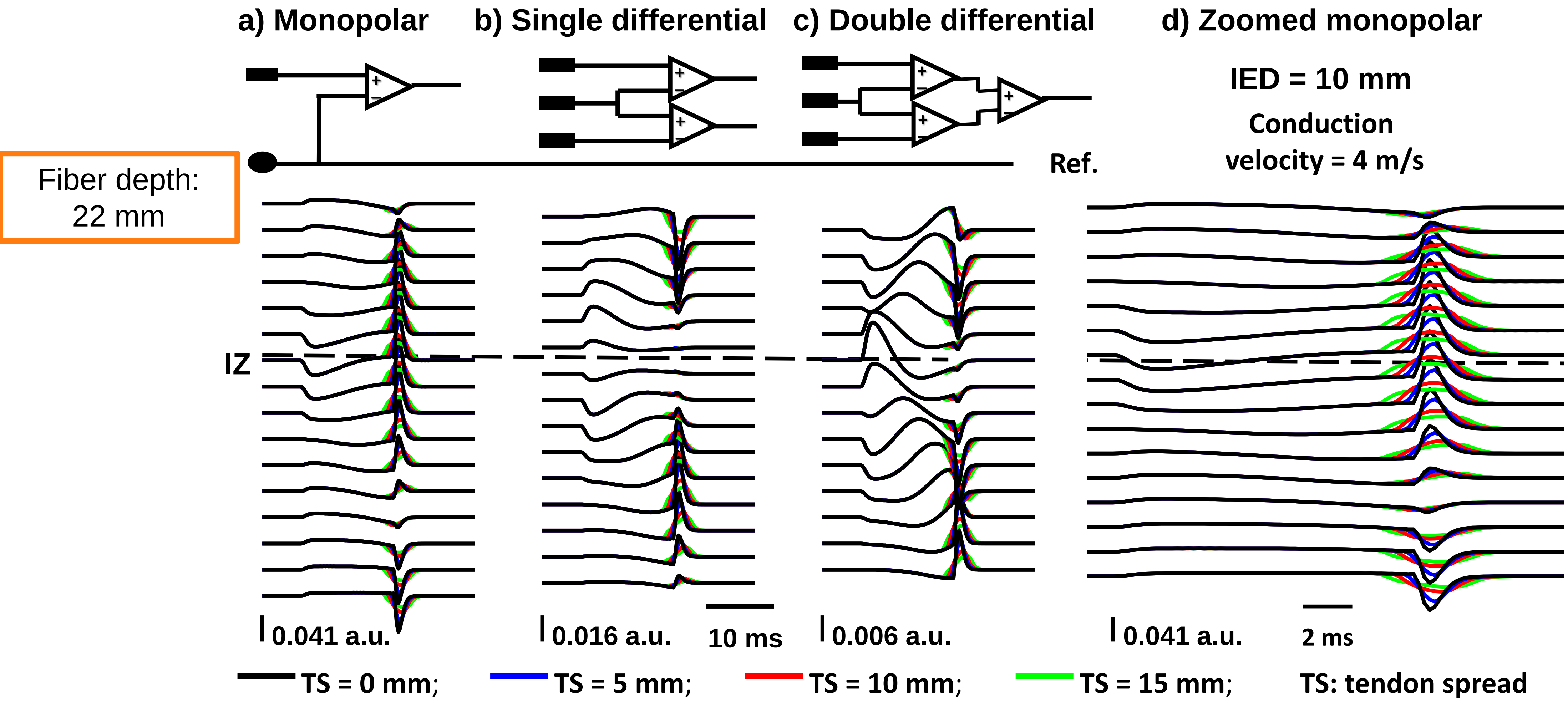
Electrode configuration

Fiber depth:
4 mm



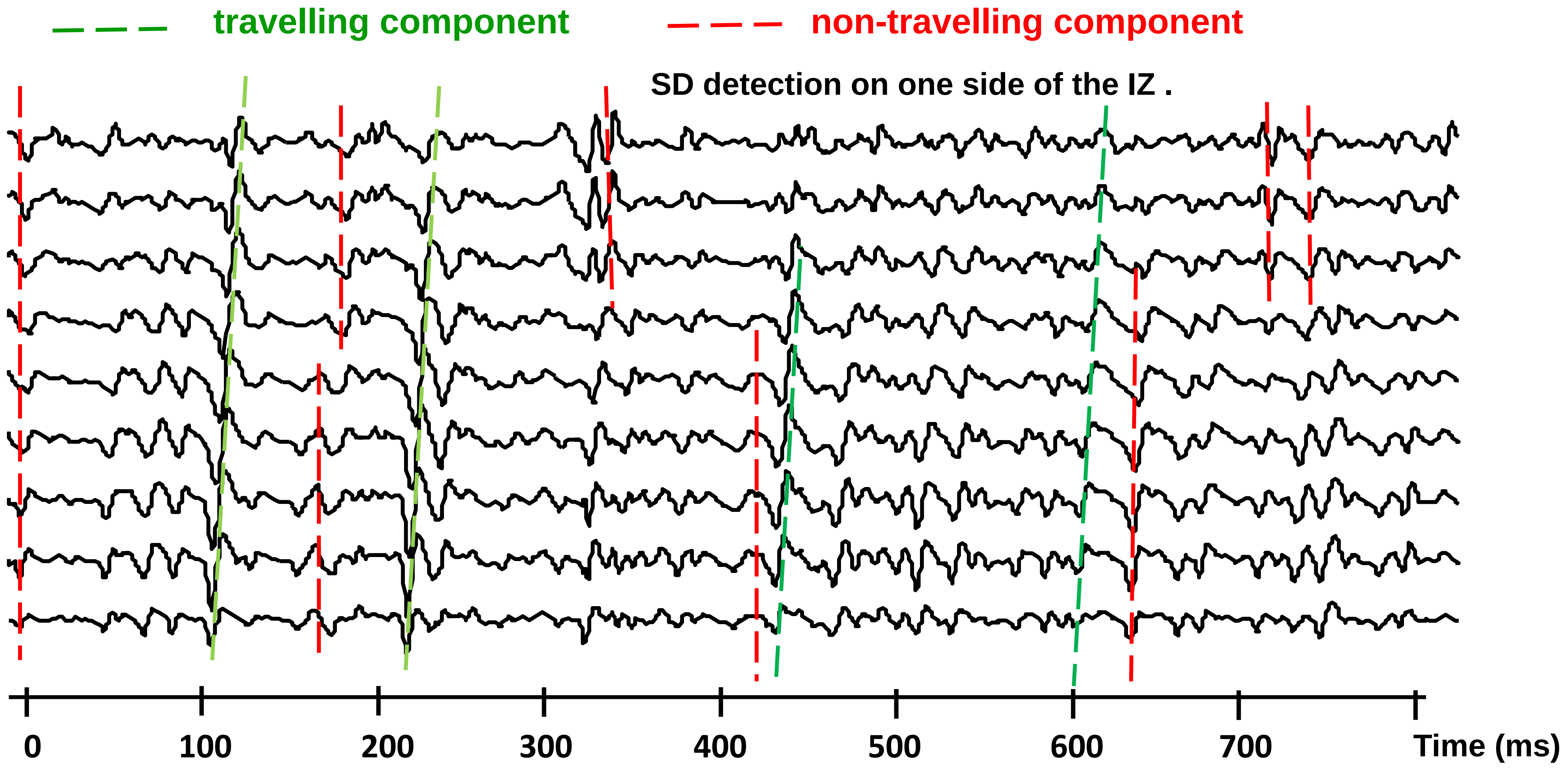
Merletti & Muceli, JEK Tutorial, Fig. 4

Electrode configuration



Merletti & Muceli, JEK Tutorial, Fig. 5

Travelling and non travelling components



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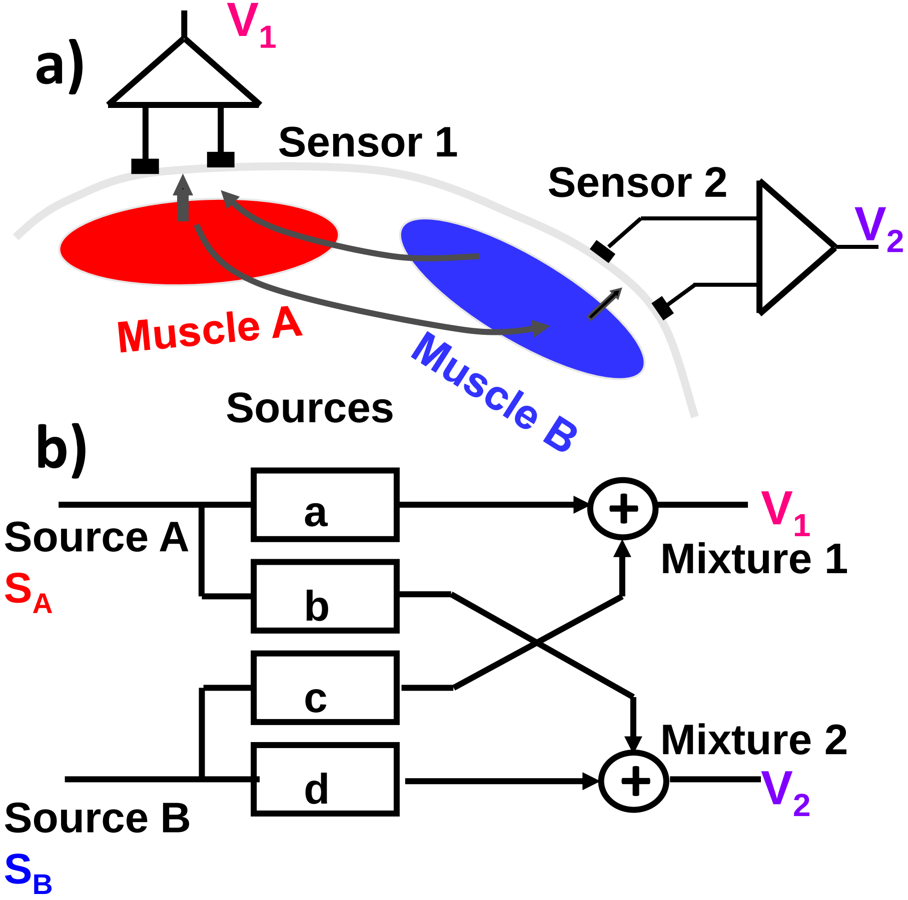
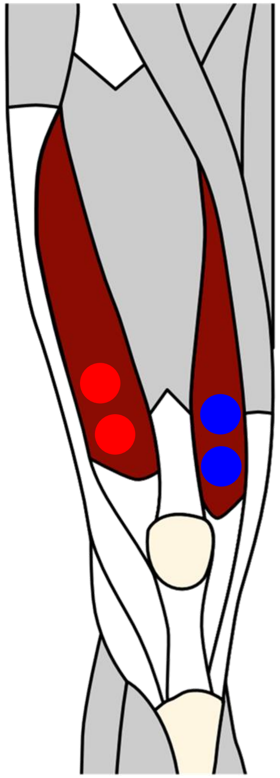
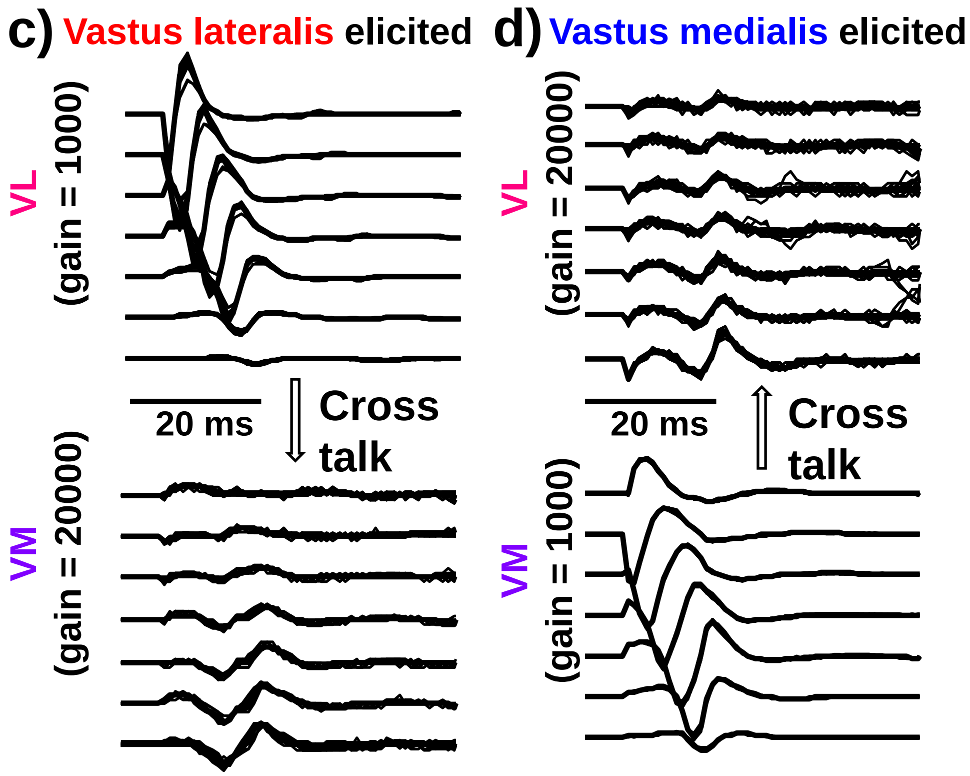
Crosstalk



Linear algebric mixture: $V_1 = a\,S_A + c\,S_B$
$V_2 = b\,S_A + d\,S_B$

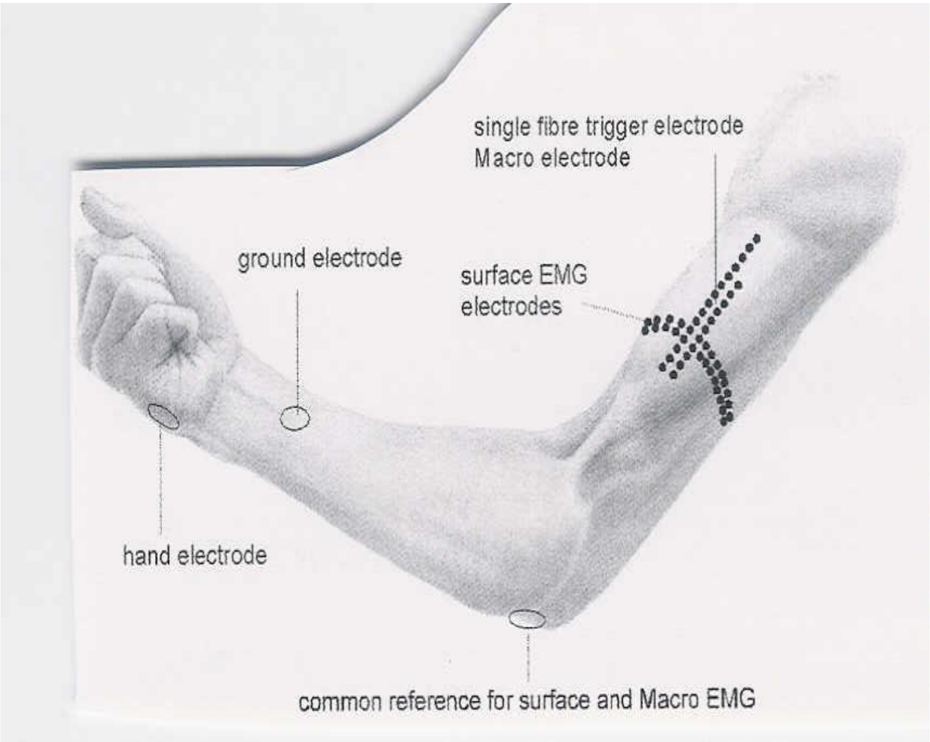


Superimposed responses to 20 electrical stimuli

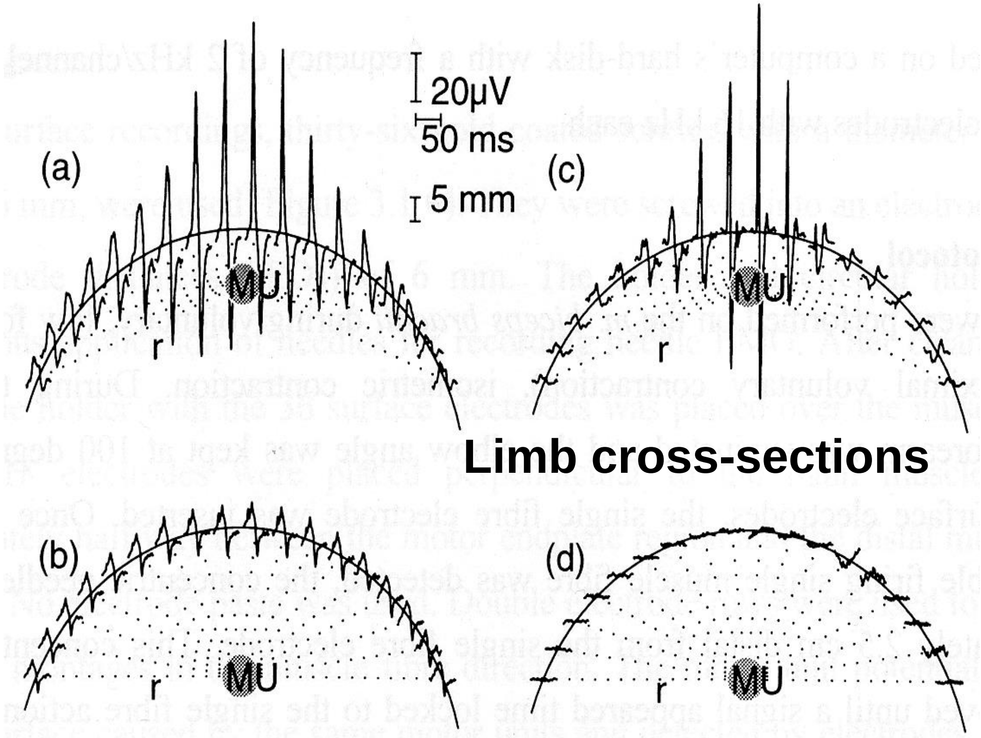


Merletti & Muceli, JEK Tutorial, Fig. 8

Electrode arrays transversal to the fiber direction



mopol. recording longitudinal SD recording



Limb cross-sections

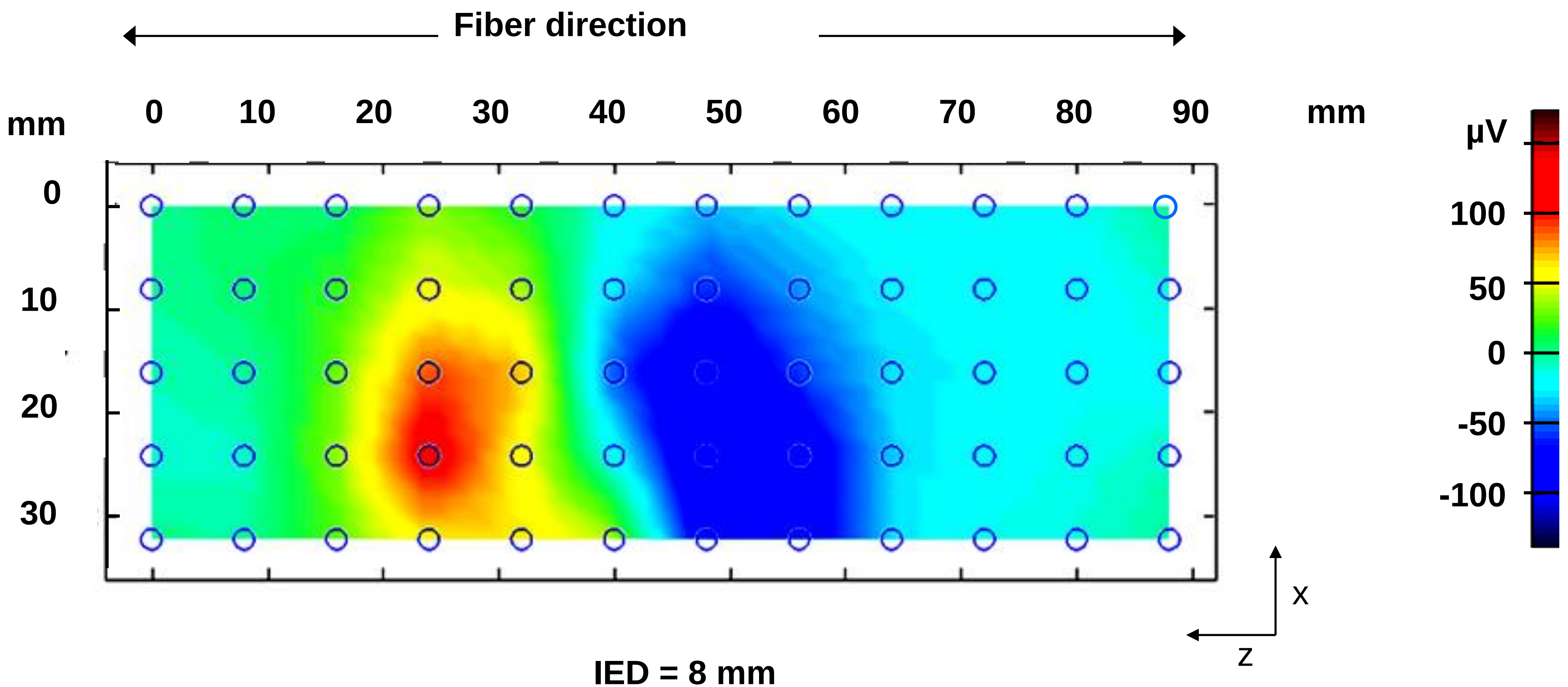
superficial MU

deep MU

SD recordings are more selective

Roeleveld et al, Acta Physiol Scand, 1997

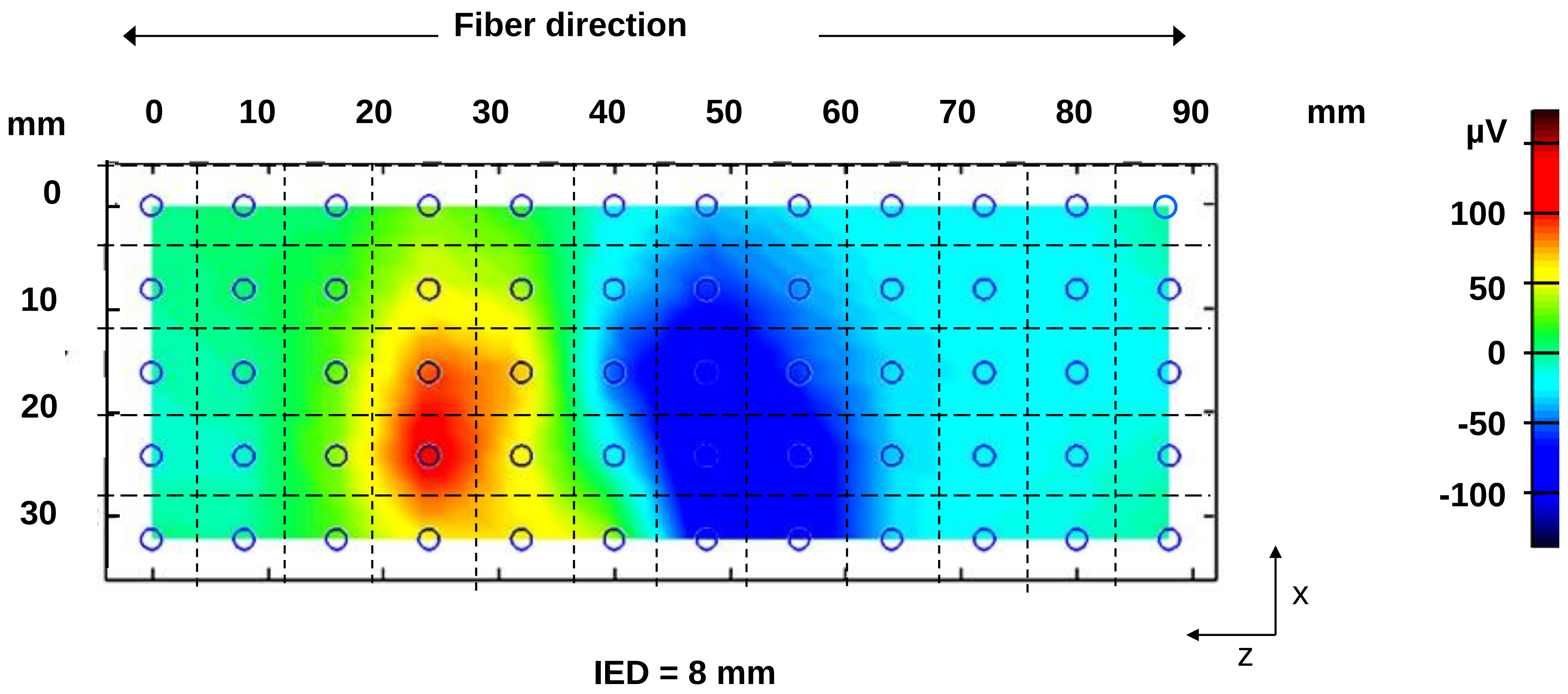
The EMG image



IED = 8 mm

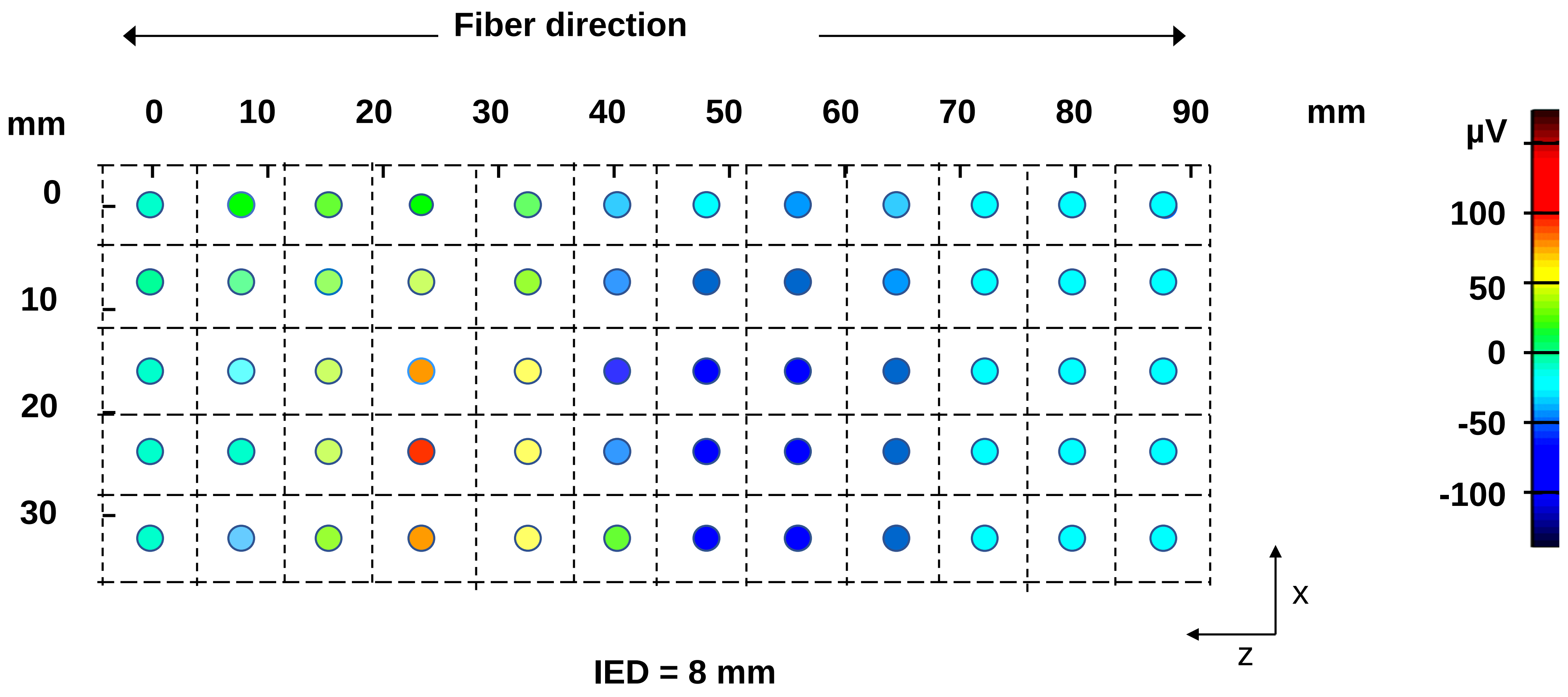
Merletti & Muceli, JEK Tutorial, Fig. 9

The EMG image



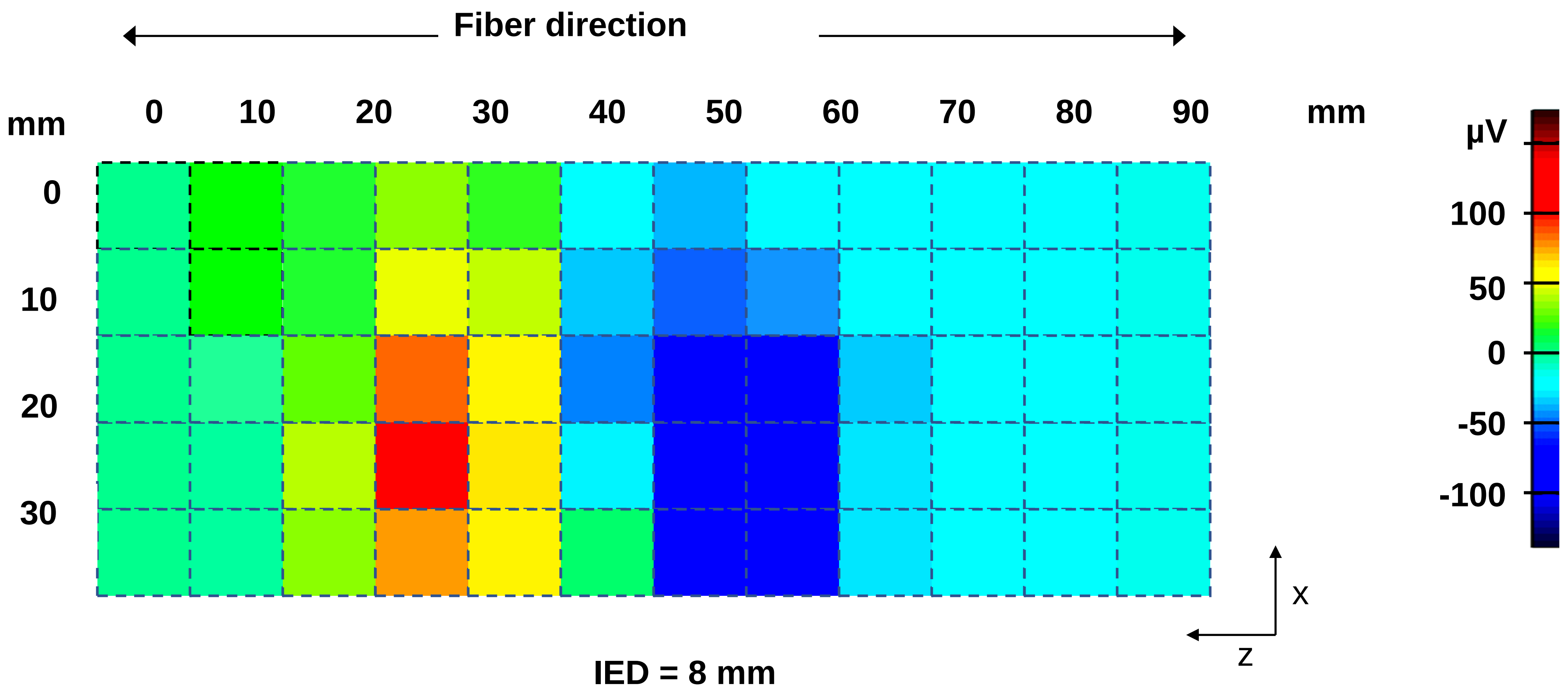
Merletti & Muceli, JEK Tutorial, Fig. 9

The EMG image



Merletti & Muceli, JEK Tutorial, Fig. 9

The EMG image

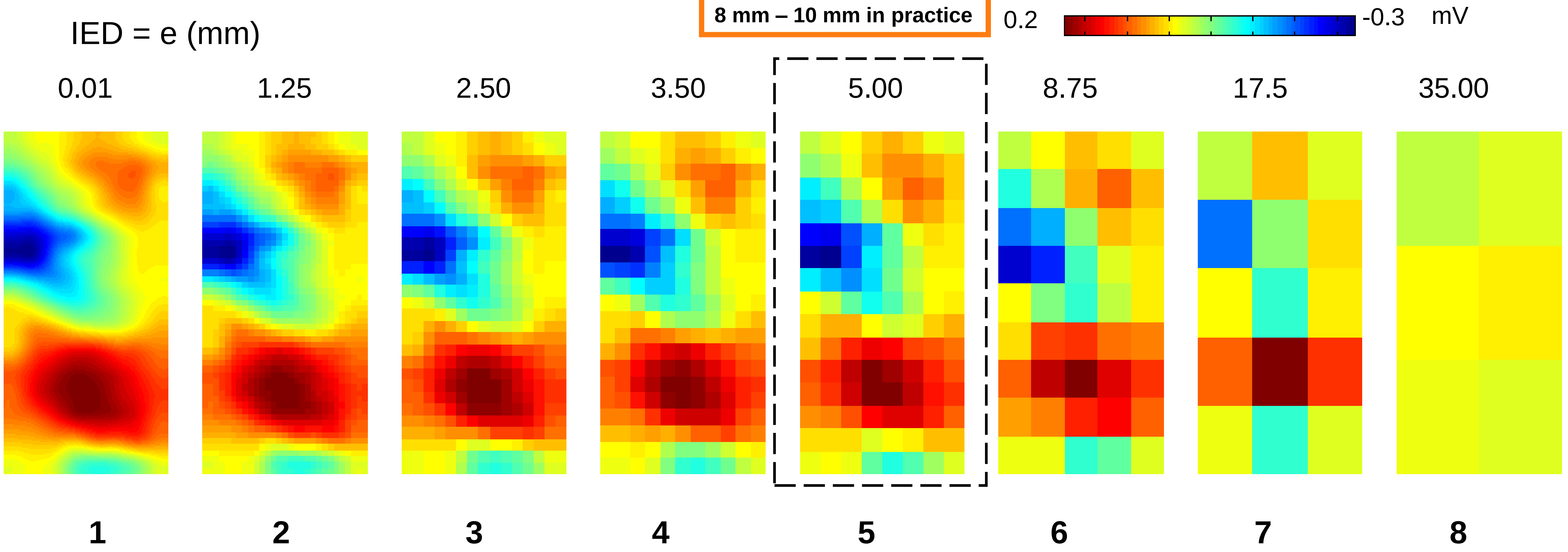


Merletti & Muceli, JEK Tutorial, Fig. 9

Image interpolation in space

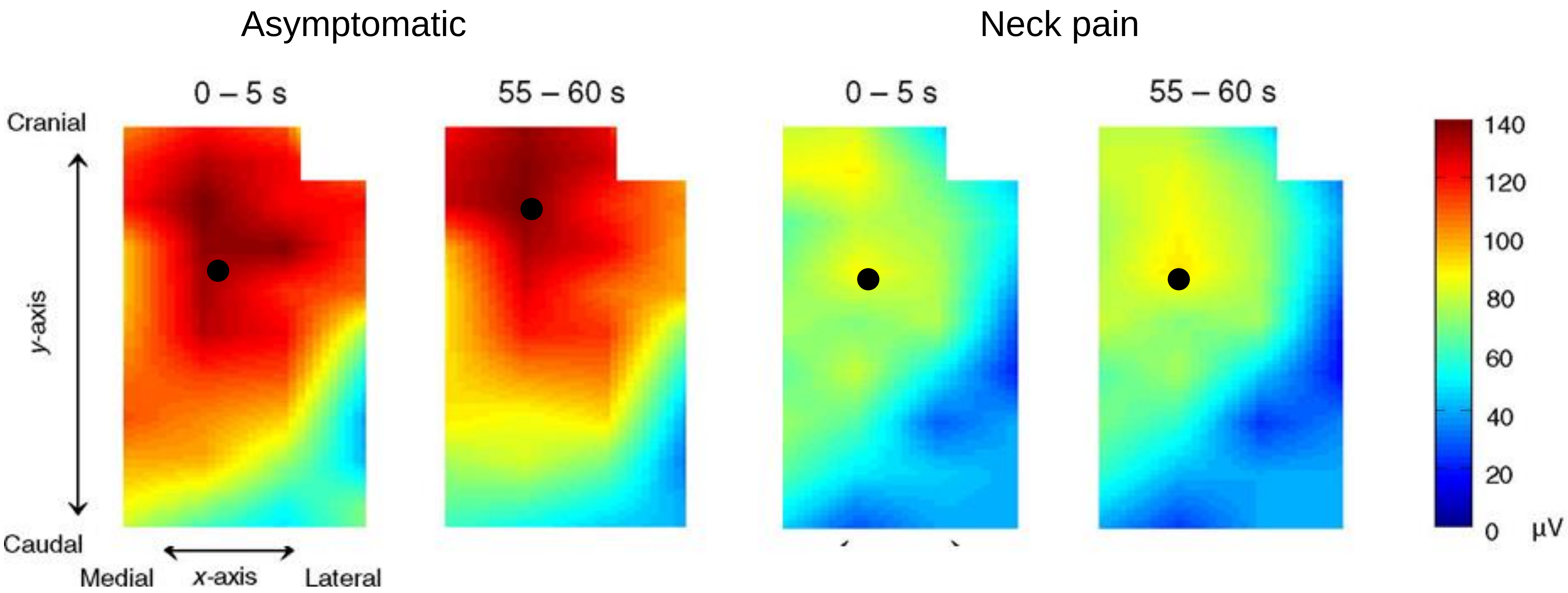
Interelectrode distance
1000/200 mm = 5 mm

8 mm – 10 mm in practice



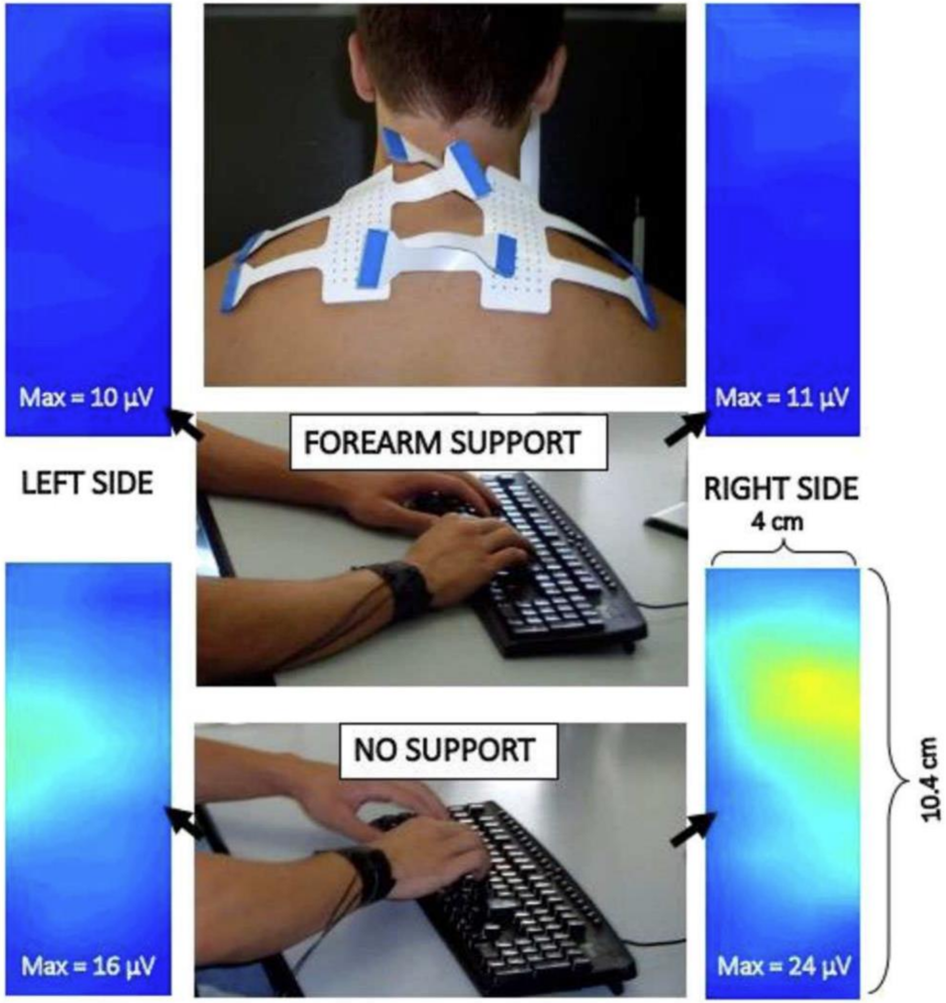
Merletti & Muceli, JEK Tutorial, Fig. 15

Pain-related changes in muscle activation



Falla & Gallina, J Electromyogr Kinesiol, 2020

Applications in ergonomics



Campanini et al, Front Neurol, 2020

Best practice

- The proper detection technique depends on the application
  - Single channel (to detect sEMG timing, envelope, amplitude and spectral variables)
  - Multiple single channel detection systems on different muscles
  - Few channels on the same muscle (such as two SD or DD channels to estimate muscle fiber conduction velocity),
  - Linear electrode arrays (to identify the innervation zone and its shifts with movement, fiber length, muscle fiber conduction velocity, optimal position of a single electrode pair)
  - Many channels from an electrode grid (to document compartmentalization of activity, to localize reflex activity, to identify a region of activity, its extension, centroid, etc).
- Electrode systems (size, inter-electrode distance) determine features of EMG signals in time and space. Must be reported!

MARIE CURIE ACTIONS

European Commission | Horizon 2020 European Union funding for Research & Innovation

CHALMERS UNIVERSITY OF TECHNOLOGY

Thank you for your attention

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International Society of Electrophysiology and Kinesiology

Politecnico di Torino

Tutorial. Surface EMG detection, conditioning and pre-processing: Best practices

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OUTLINE

Introduction and Aim

Block diagram of a sEMG acquisition system

Common technical issues

Best practices

Conclusions

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INTRODUCTION AND AIM

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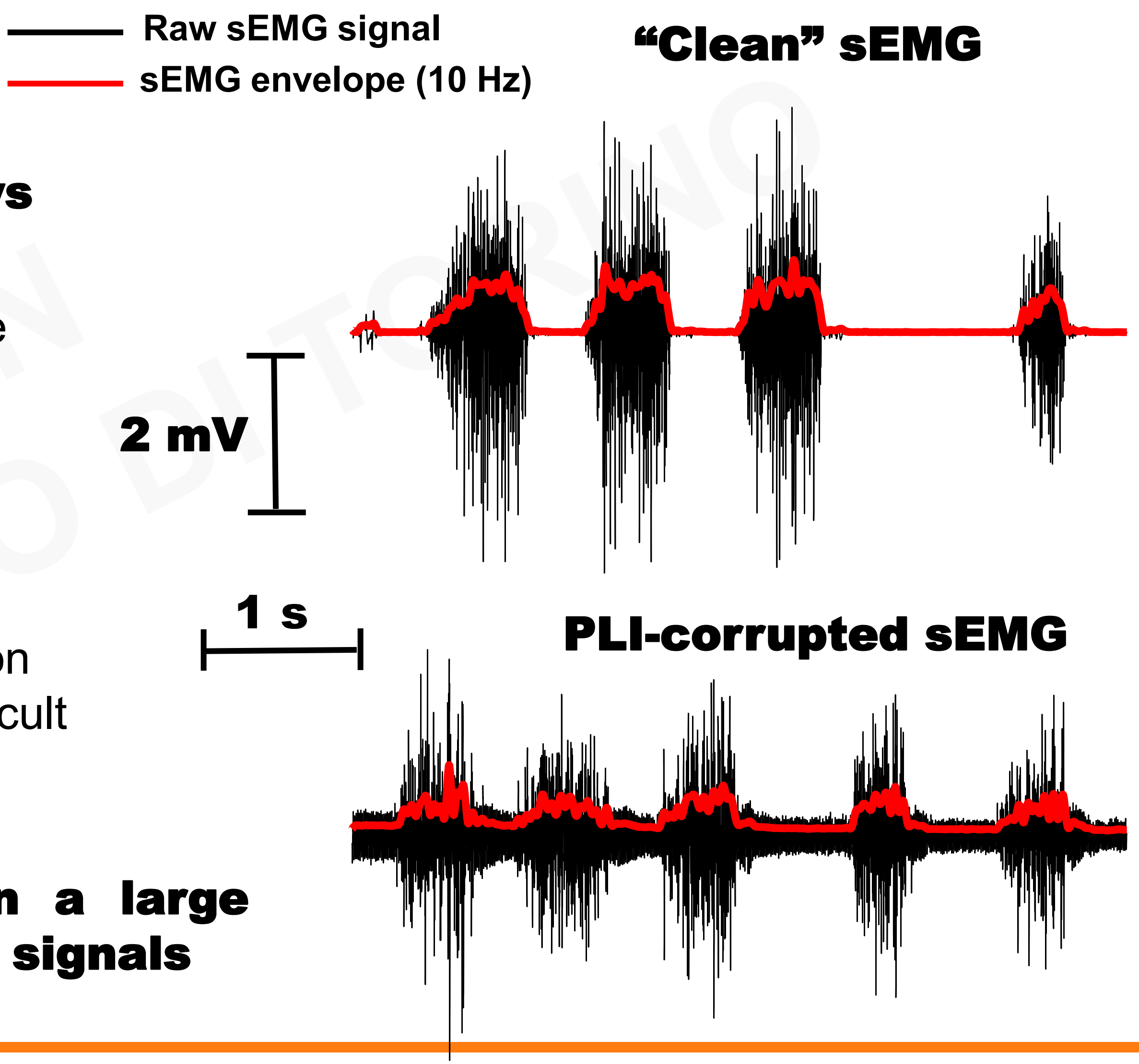
INTRODUCTION: DETECTION OF HIGH-QUALITY SIGNALS

Q: Why is it important?

Collecting high quality sEMG signals is always preferable because:

- It is difficult and not always possible (e.g. for real time applications) to ‘’clean’’ sEMG signals
- The quality of information extracted from raw sEMG signals may be affected by noise and interference
- Once sEMG signals have been processed, information on the quality of raw data may be lost→it may be difficult to explain unexpected results

These facts are particularly relevant when a large amount of information is collected (HD-sEMG) signals



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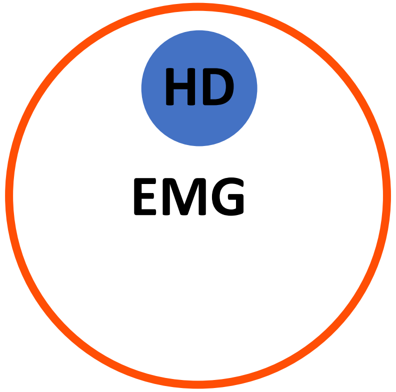
HD-sEMG

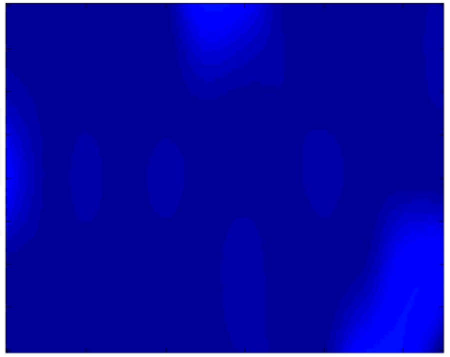


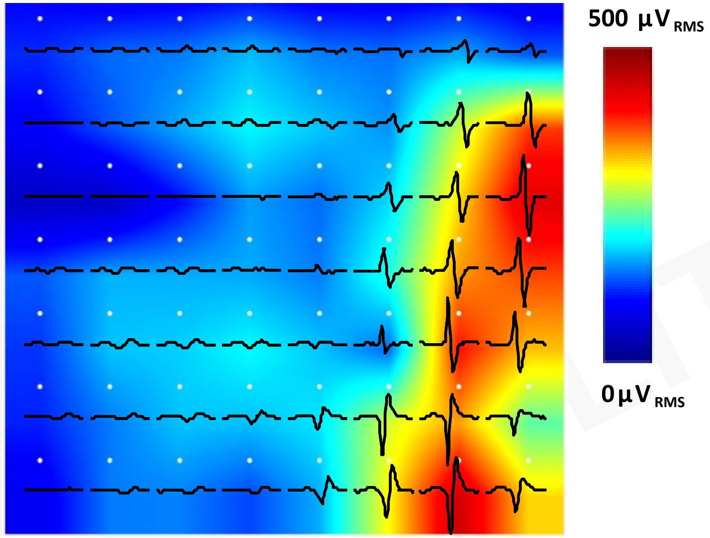
High-Density EMG is a powerful technique allowing to

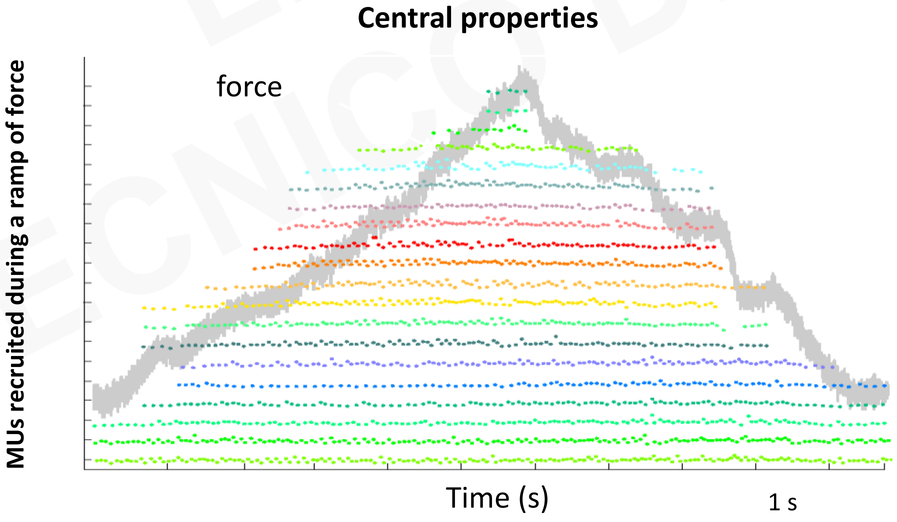
- Evaluate spatio-temporal distribution of muscle activity and its changes in time
- Investigate peripheral and central properties of the neuromuscular system

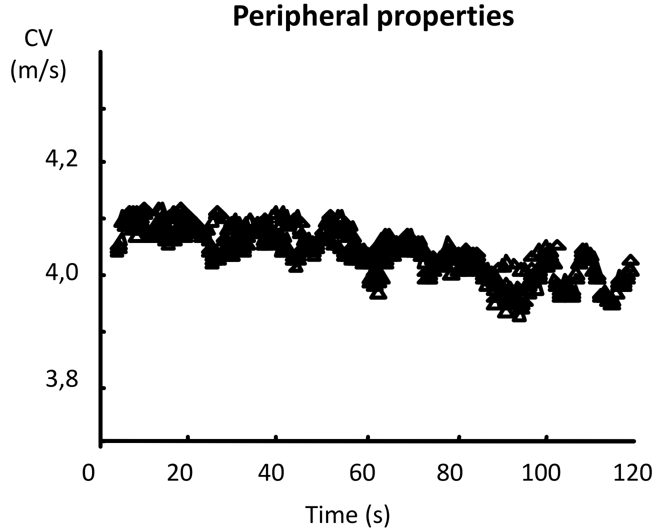
Some application fields are:

- Disease/treatment assessment
- Ergonomics
- Musculo-skeletal models
- Biofeedback
- Prosthesis control
- Human-Computer Interactions









[Merletti, Holobar, and Farina, JEK, 2008]

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1859

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#ISEKtutorials

THIS PRESENTATION IS AIMED TO....

- **Describe the basic functioning of a sEMG acquisition system**
- **Describe common technical issues related to the sEMG acquisition**
- **Provide a basic technical background on sEMG acquisition devices**
- **Contribute to mold a technical background and a common language shared between engineers and clinicians**

Technical aspects are treated in a simplified way

A Q&A presentation format is used

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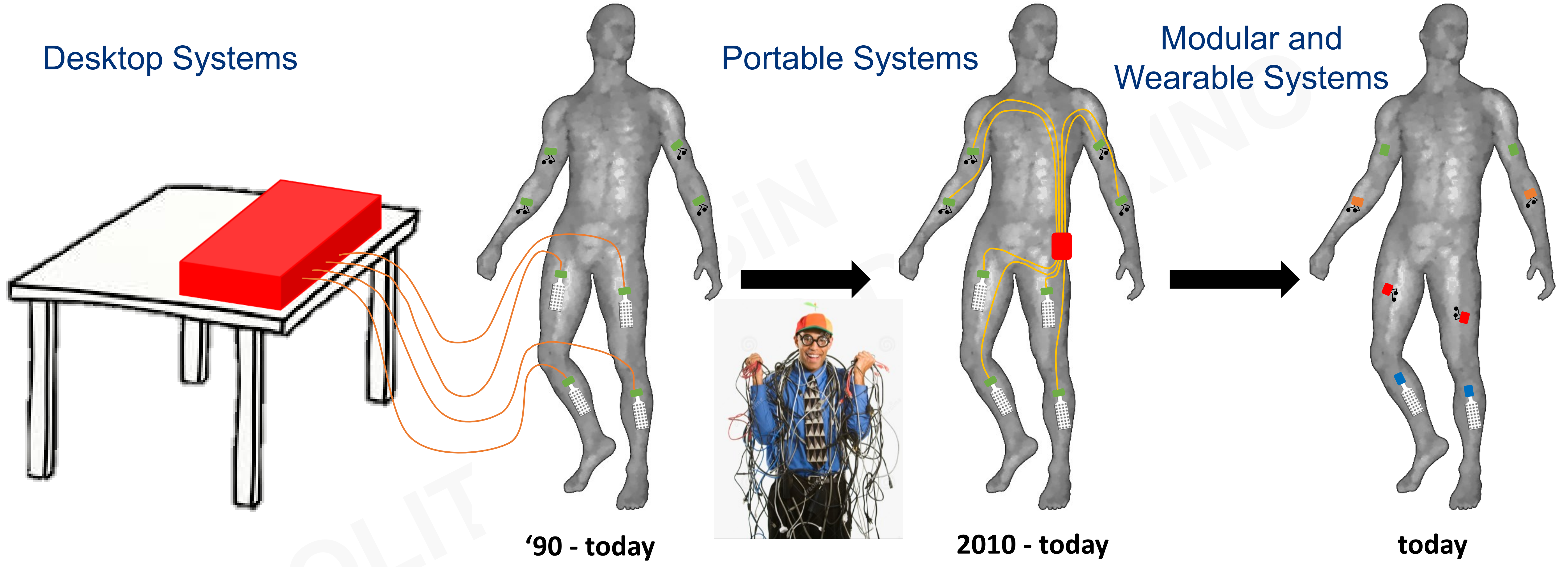
TECHNOLOGICAL STATE OF THE ART EVOLUTION



EMG Acquisition System Electrode Connector grid of sEMG electrodes bipolar sEMG electrodes

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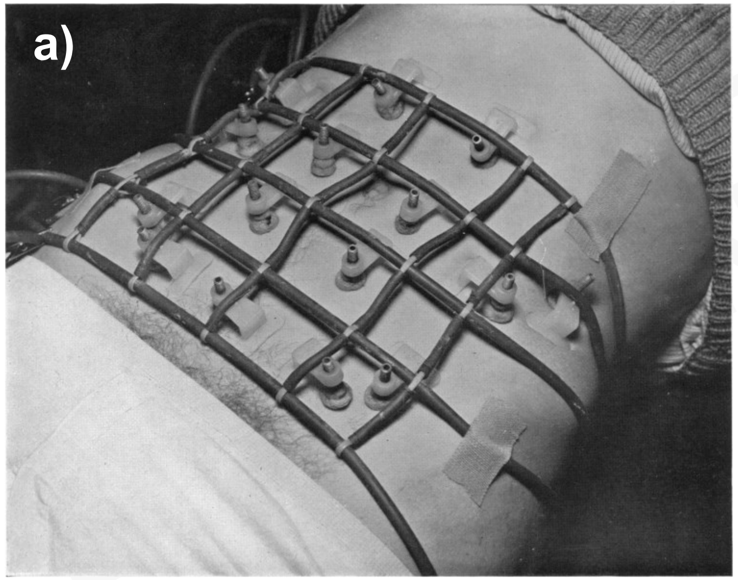
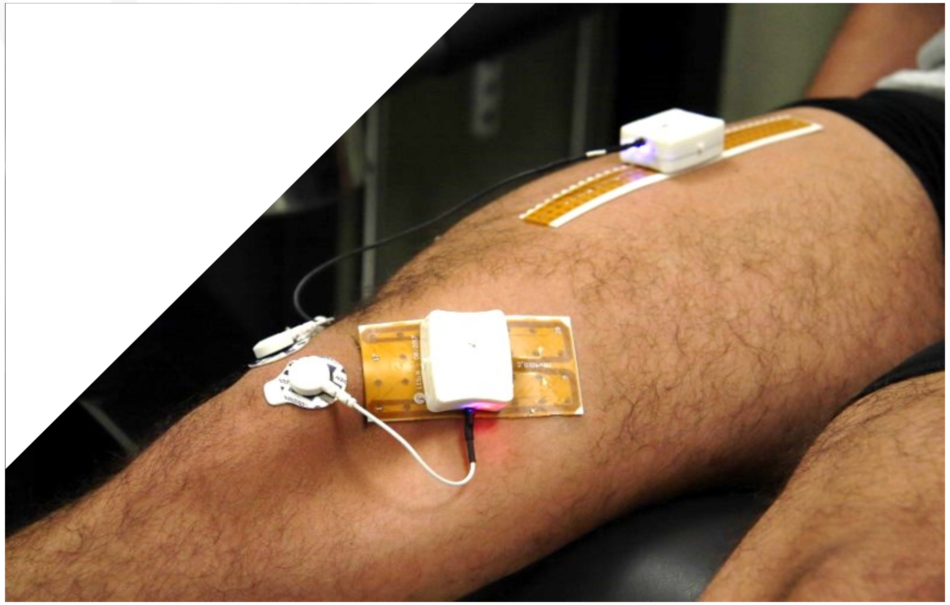
TECHNOLOGICAL STATE OF THE ART

Throughout this presentation we will address the motivations beyond this technological evolution and some of the open challenges that still need the operator's attention and research work



[Floyd and Silver. J. Anat, 1950]



[Tutorial, Merletti and Cerone, JEK, 2020]

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BLOCK DIAGRAM OF A sEMG ACQUISITION SYSTEM

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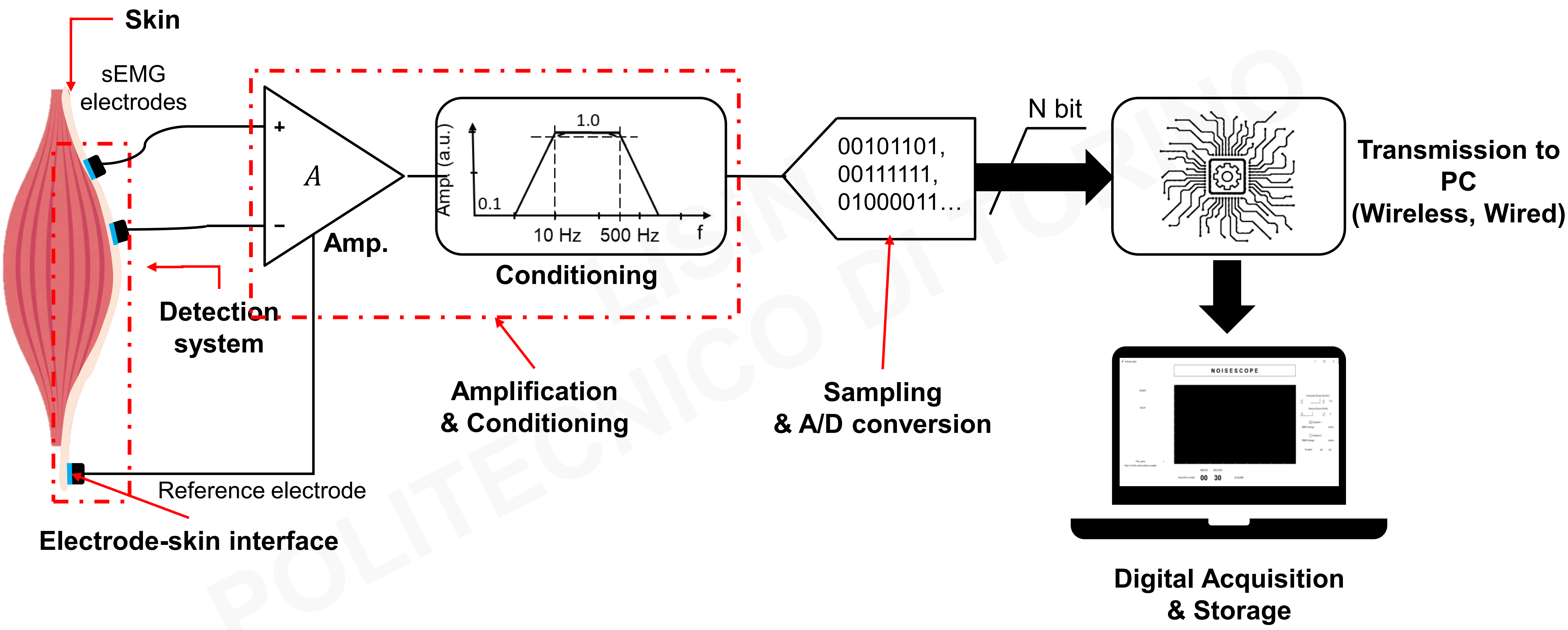
sEMG ACQUISITION SYSTEM: BLOCK DIAGRAM



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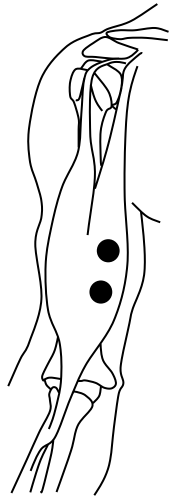
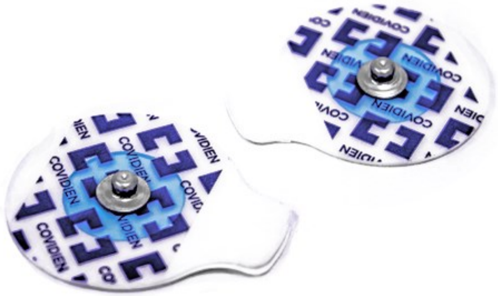
sEMG ACQUISITION SYSTEM: THE ELECTRODE

Bipolar electrodes

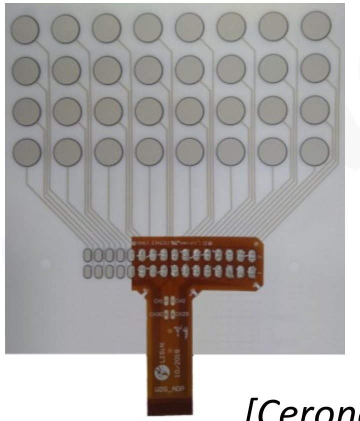


Dry bar electrodes (Delsys)

Bipolar pre-gelled electrodes (Covidien)

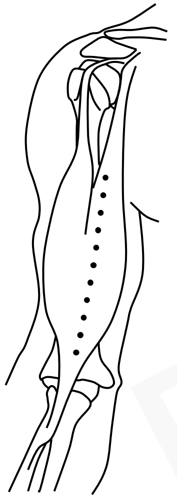


Dry, wearable grid



[Cerone et al. IEEE TNSRE 2021]

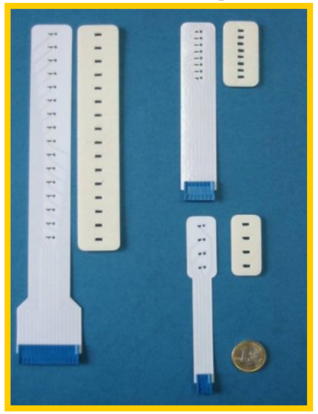
Array of electrodes



Dry Electrode arrays with silver bars

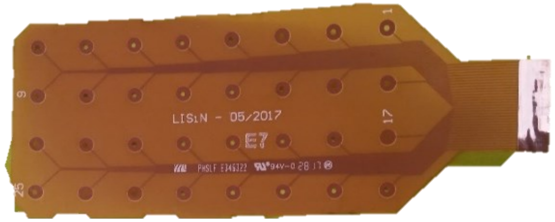
Adhesive arrays with Gel

(OT Bioelettronica, Spes Medica)



Adhesive grid

(with conductive paste)



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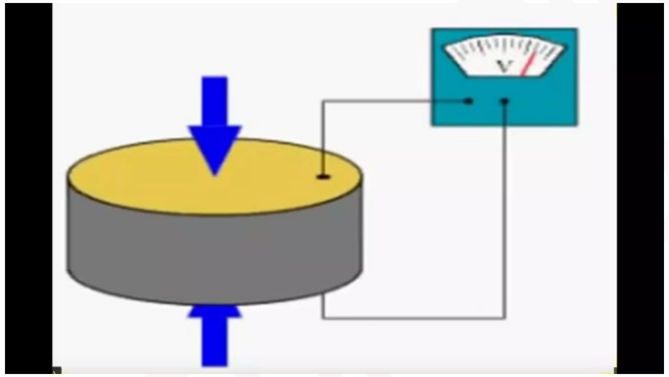
sEMG DETECTION: THE ELECTRODE-SKIN INTERFACE

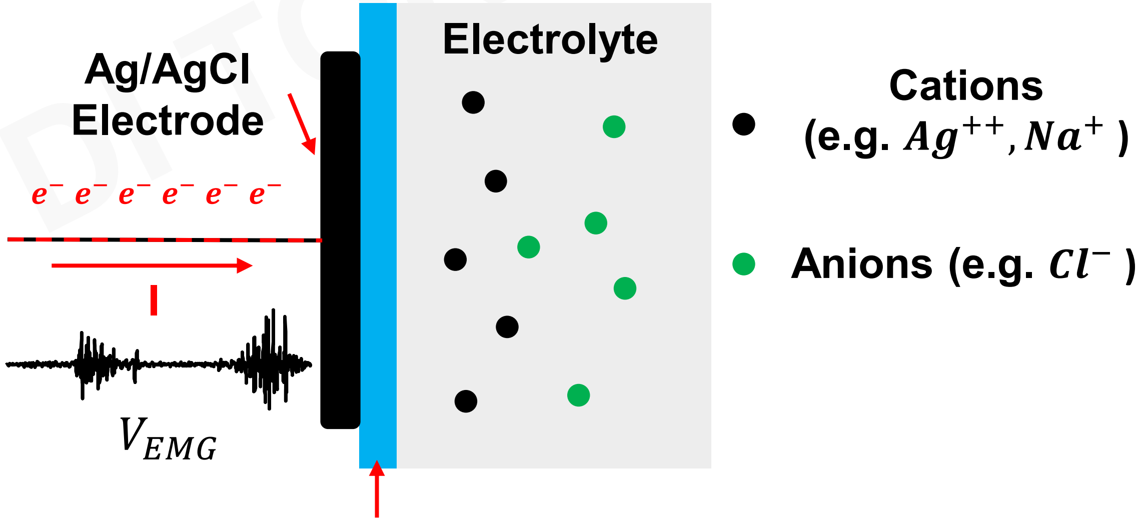
Q: What is the electrode function?

The electrode acts as an ionic transducer. It transduces ionic exchanges at the electrode-skin interface (due to the depolarization of the muscle fibers) into electric, measurable, potentials.

Piezoelectric transducer (microphone)



Ionic transducer (electrode)



Q: Why the electrode-skin interface is important?

It is important to understand the properties of the electrode-skin interface because it represents the interface between the physiological system and the acquisition device → it influences the quality of the collected signals in terms of SNR, interference, and noise.

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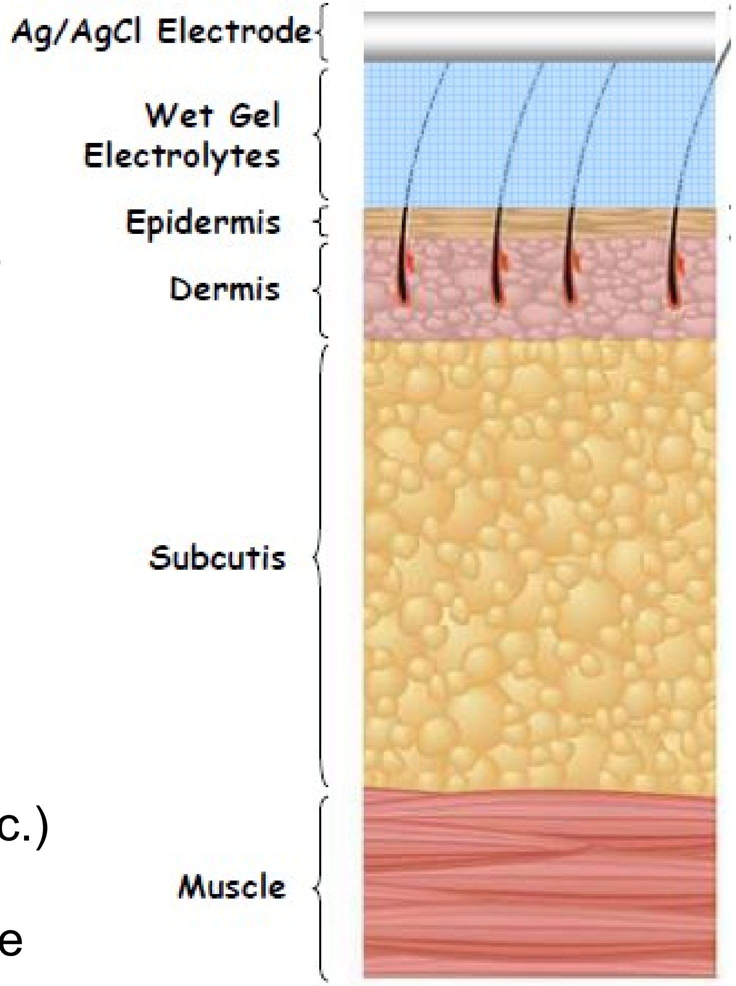
Q: What are the most important electrode properties?

- **Material**
  - Non-polarizable materials (e.g. Ag, Ag/Cl) → relatively low electrode skin impedance (tens of kΩ per cm^2)
  - Polarizable materials (e.g. gold) → higher electrode impedance (several MΩ per cm^2)
- **Size**
  - The bigger is the size, the lower is the electrode impedance (less problems related to PLI, noise etc.)
  - The bigger is the size, the bigger is the IED and the detection volume
  - Average effect on the collected sEMG signals
- **Biocompatibility**
  - they shall not induce adverse events (e.g. allergic reactions, skin irritation etc.)
- **Type of support and interaction medium:** Dry (no medium), Gelled, Conductive paste, textile support, adhesive support etc.



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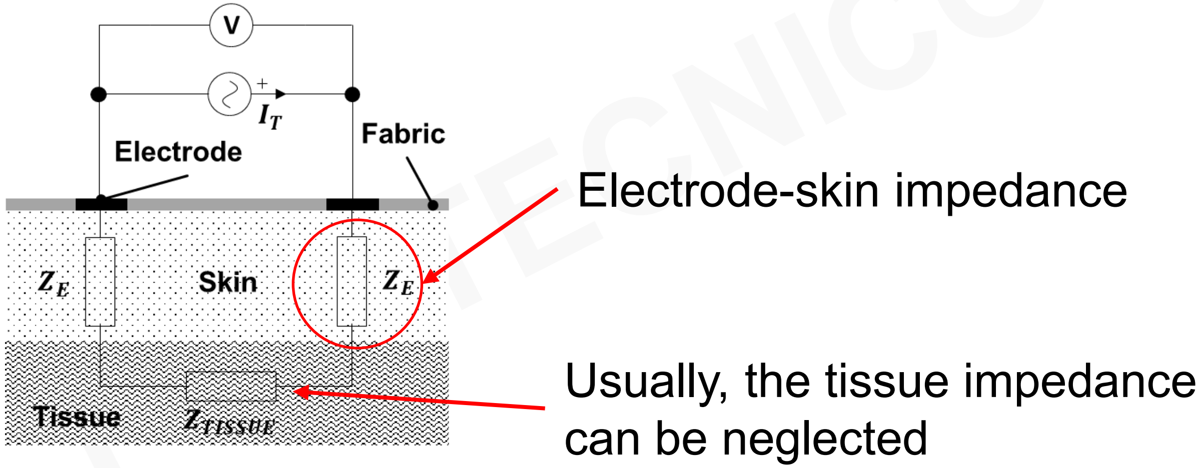
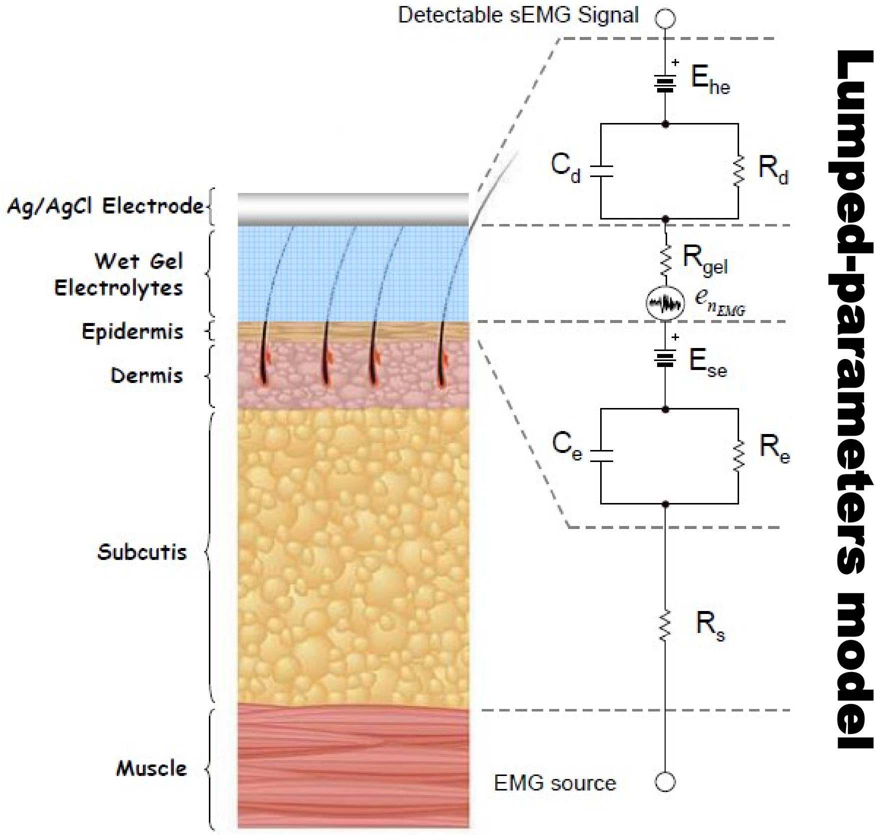
sEMG DETECTION: THE ELECTRODE-SKIN INTERFACE

Q: How can we characterize the electrode-skin interface?

- The electrode-skin interface is characterized in terms of electrical impedance, expressed in Ohms (Ω)
- It is possible to use:
  - A lumped-parameters model (i.e. a model using equivalent electrical components). It can be very complex
  - Experimental data collected by means of an impedance-meter





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sEMG AMPLIFICATION AND CONDITIONING

Q: Why amplifying and conditioning a biological signal?

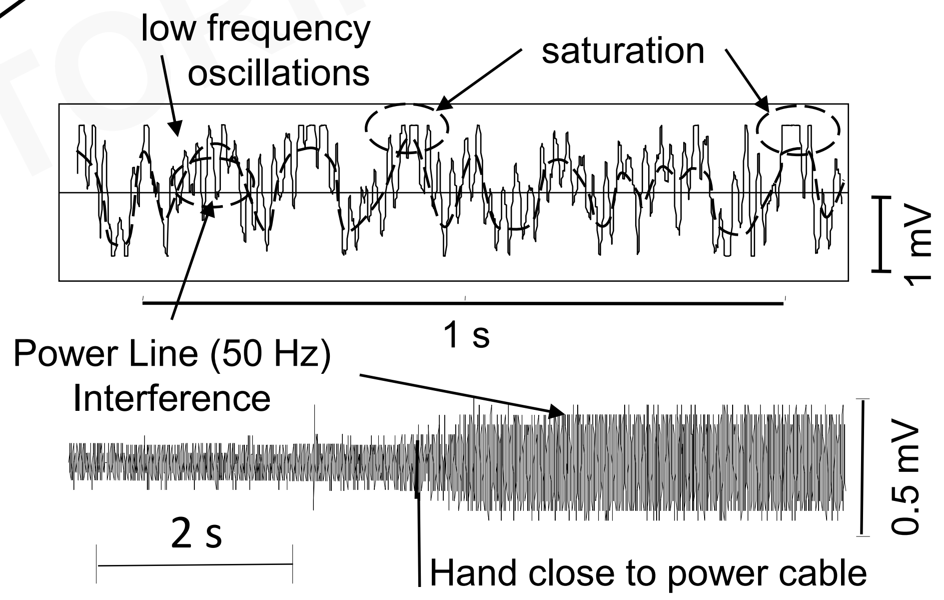
sEMG signals characteristics:

- sEMG Amplitude: up to 2-3 mV_{pp}
- sEMG bandwidth: 10 Hz – 500 Hz

$$SNR = \frac{V_{EMG}}{Vn} \approx 10^{-3}$$!!!

Additive disturbances characteristics:

- Noise and interference amplitude (Vn): up to some Volts
- Noise and interference bandwidth
    - baseline shift due to movement artefacts – up to few Hertz
    - Power line interference – 50 Hz/60Hz



[Tutorial, Merletti and Cerone, JEK, 2020]

Actually, it is impossible to distinguish sEMG signals → It is needed to Amplify (V_{EMG}) the signal of interest and Reject the unwanted signals (V_n)

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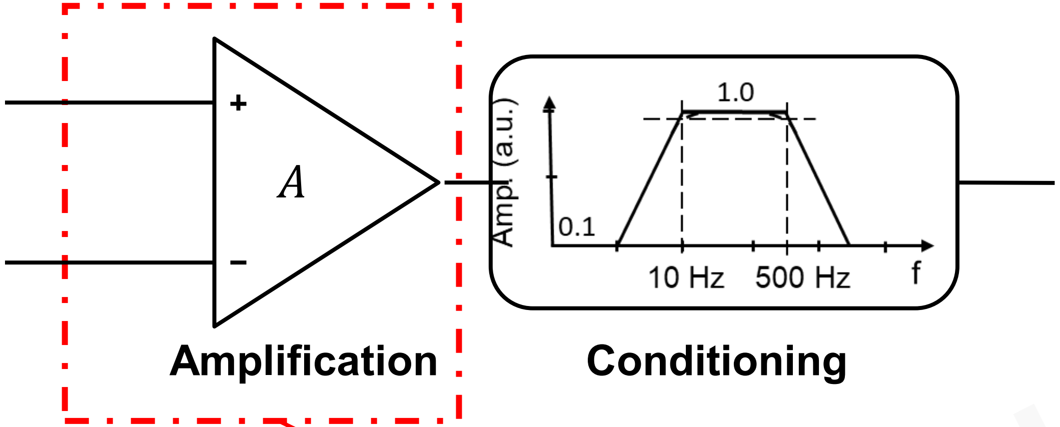
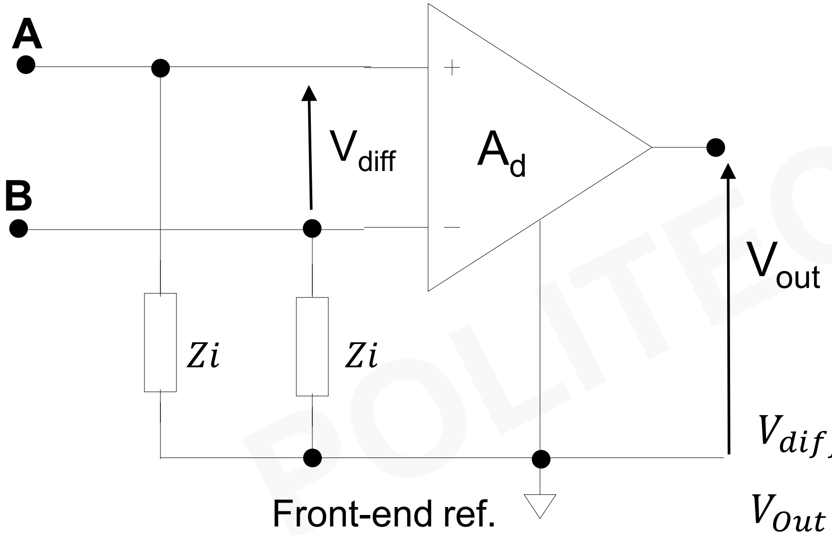
sEMG AMPLIFICATION AND CONDITIONING



Simplified input-output model



$$V_{diff} = V_A - V_B$$

$$V_{Out} = V_{diff} \times A_{d_{EMG}}$$

A differential amplifier allows to amplify the difference of the potentials collected at its inputs (A and B).

Q: What are the most important parameters of a biological signal amplifier?

- Ad – differential mode amplification – sEMG signals will be amplified by a factor of Ad.
- Zi – input impedance – it is the impedance that models the input stage of the differential amplifier. It “interacts” with the detection system
- CMRR (not discussed within this presentation)

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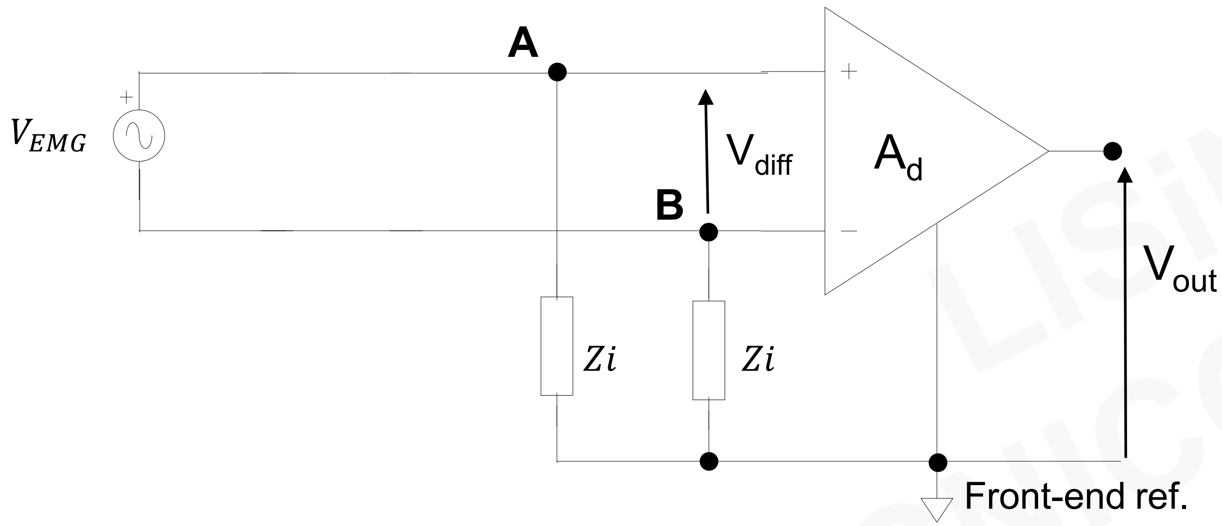
sEMG AMPLIFICATION AND CONDITIONING

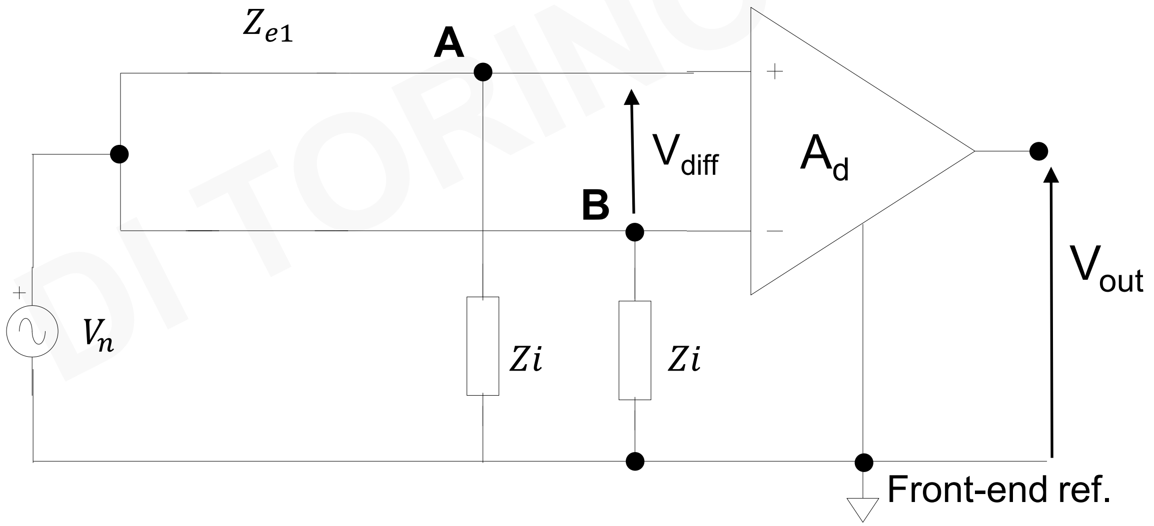
V_{EMG} amplification: ideal case



$$V_{diff} = V_A - V_B = V_{EMG}$$

$$V_{Out} = V_{diff} \times A_d = V_{EMG} \times A_d$$

V_n rejection: ideal case



$$V_n = V_A = V_B$$

$$V_{diff} = V_A - V_B = 0$$

$$V_{Out} = V_{diff} \times A_d = 0$$

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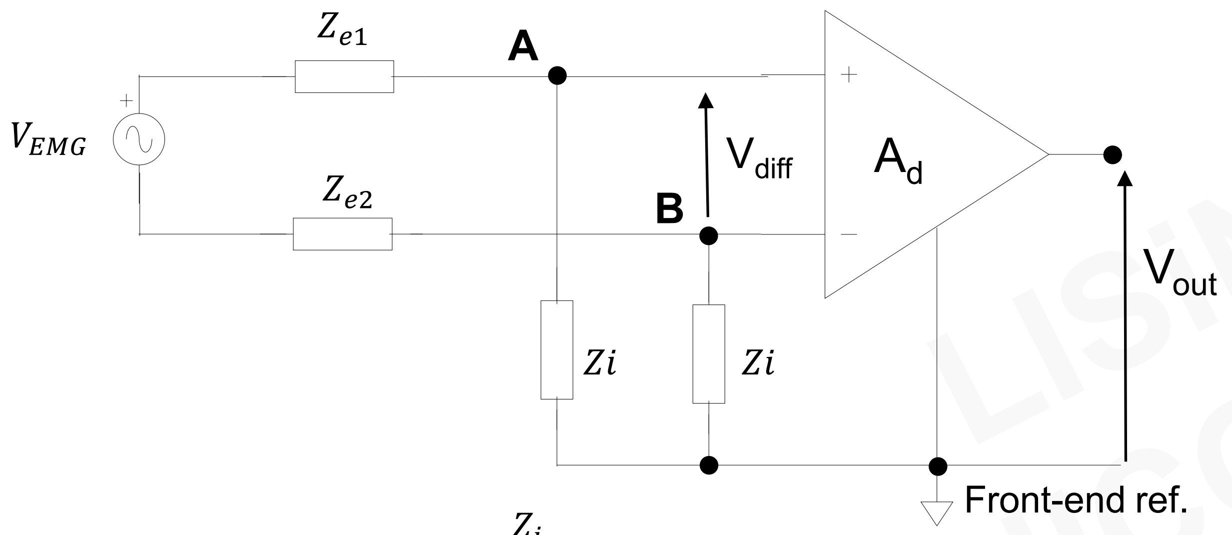
sEMG AMPLIFICATION AND CONDITIONING

V_{EMG} amplification: real case

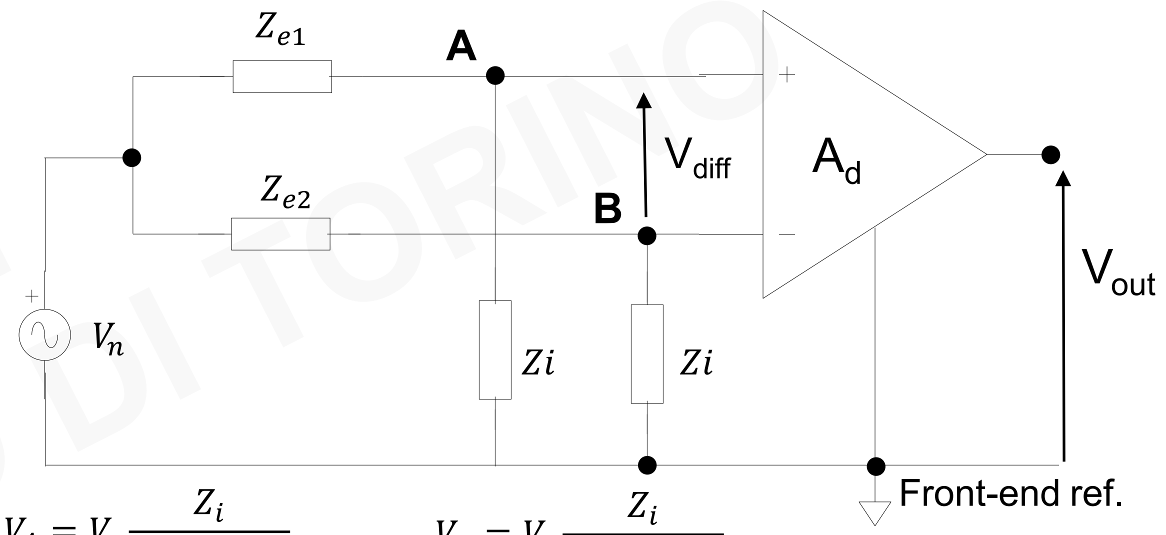


$$V_{diff} = V_A - V_B = V_{EMG} \frac{Z_i}{(Z_i + Z_e)}$$

$$V_{out} = V_{diff} \times A_d = V_{EMG} \times \frac{Z_i}{(Z_i + Z_e)} \times A_d$$

Lowering the electrode-skin impedance (Z_e), allows to avoid attenuation of the input signal, increasing the SNR

V_n rejection: real case



$$V_A = V_n \frac{Z_i}{(Z_i + Z_{e1})} \qquad V_B = V_n \frac{Z_i}{(Z_i + Z_{e2})}$$

$$V_{diff} = V_A - V_B = V_n \frac{Z_{e1} - Z_{e2}}{(Z_i)} \qquad V_{out} = V_{diff} \times A_d = V_n \frac{Z_{e1} - Z_{e2}}{(Z_i)} \times A_d$$

Lowering the electrode-skin impedance (Z_e), allows minimize effect of common mode signals (e.g. 50 Hz) at the amplifier's input

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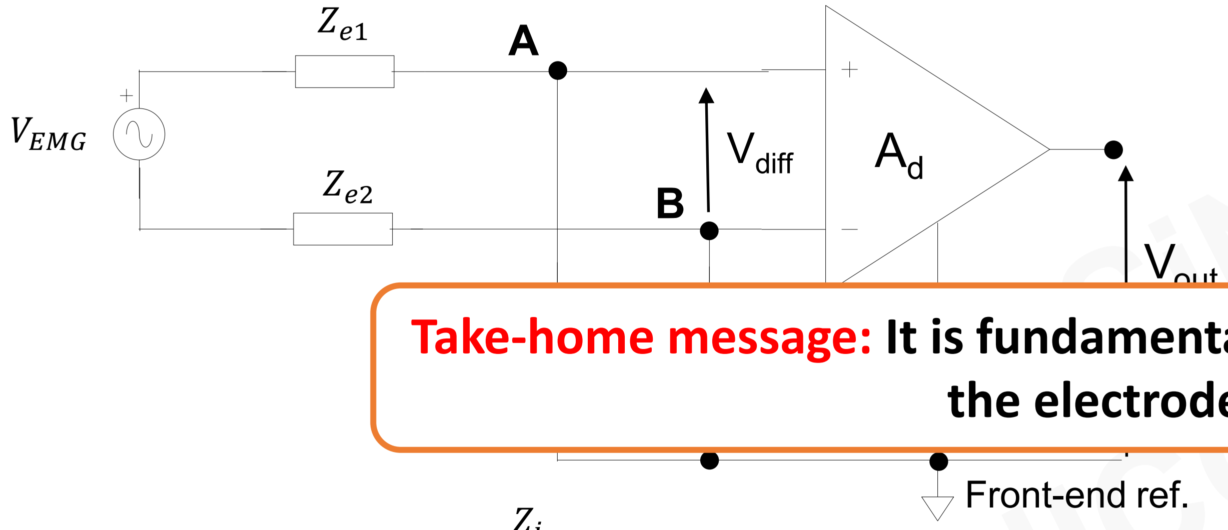
sEMG AMPLIFICATION AND CONDITIONING

V_{EMG} amplification: real case



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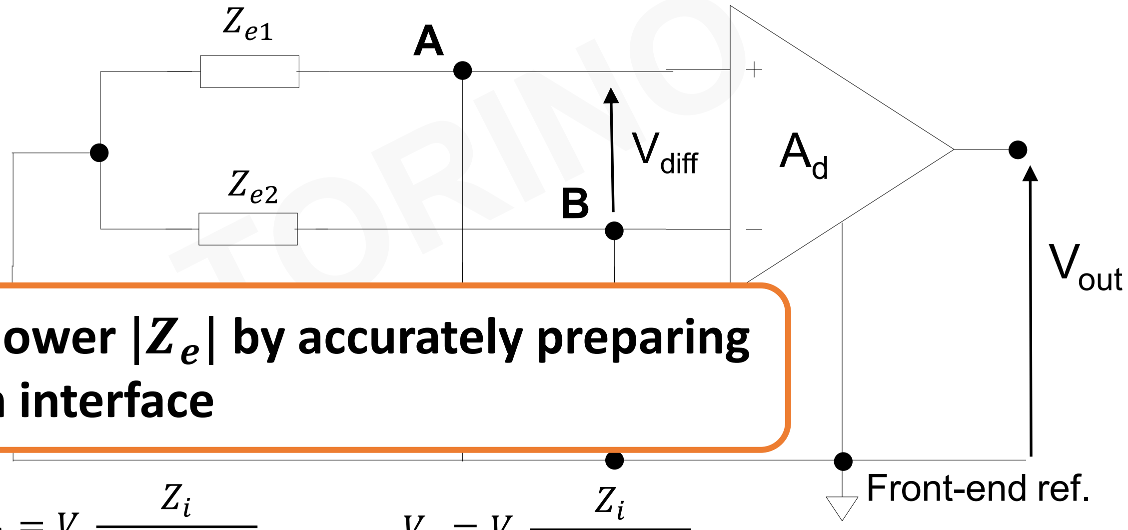
V_n rejection: real case



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Lowering the electrode-skin impedance (Z_e), allows minimize effect of common mode signals (e.g. 50 Hz) at the amplifier's input

Take-home message: It is fundamental to lower $|Z_e|$ by accurately preparing the electrode-skin interface

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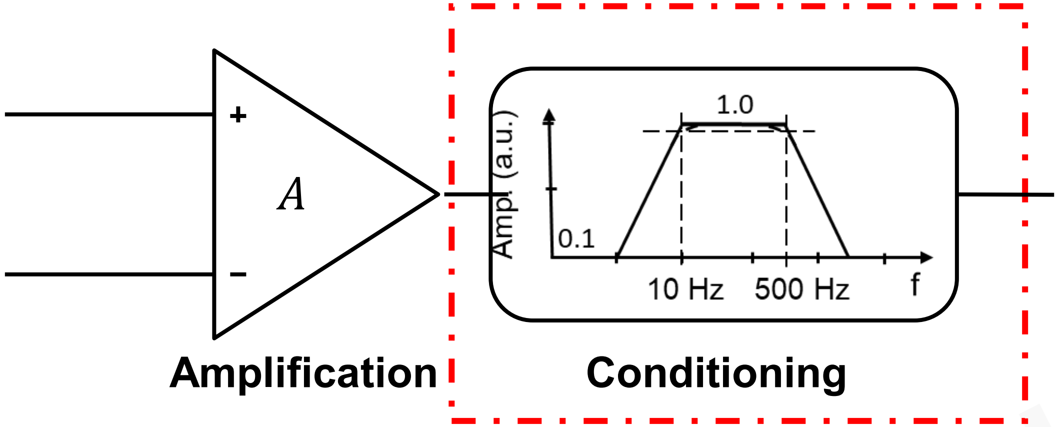
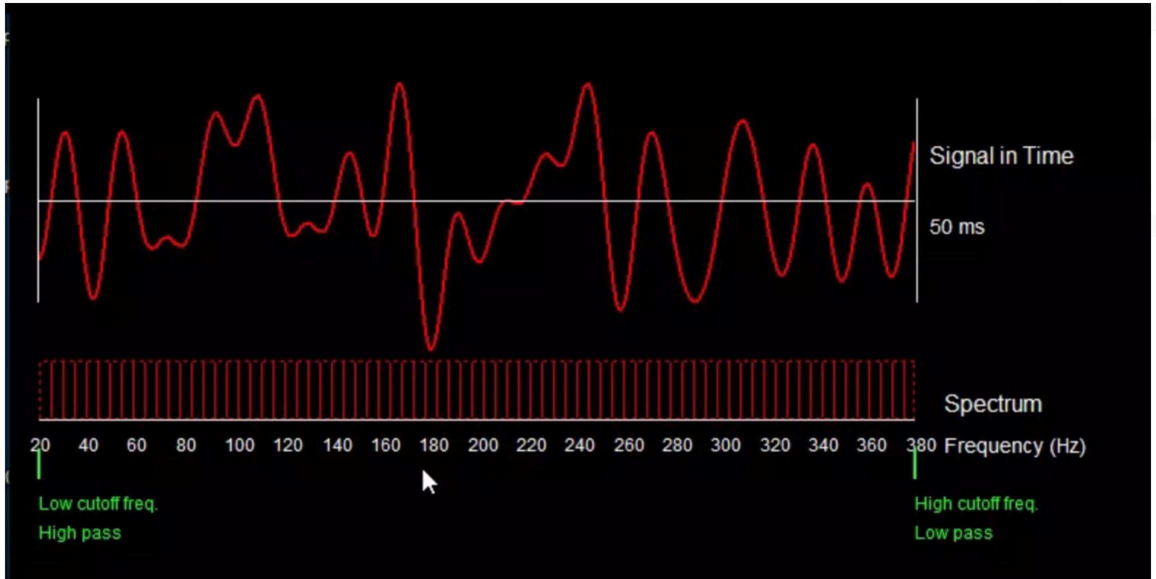
sEMG AMPLIFICATION AND CONDITIONING





[www.robertomerletti.it, R.Merletti]

sEMG bandwidth is between 10 Hz and 500 Hz

↓

there is no reason to acquire signals outside this bandwidth, because they are certainly due to disturbance (e.g. baseline shift due to movement artefacts – few Hz) or noise/interference (e.g. Neon lights interference – tens of kHz)

↓

The bandwidth of the conditioning system is the most important parameter and represents the range of frequencies that are not attenuated by the conditioning circuits

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COMMON TECHNICAL ISSUES &
BEST PRACTICES

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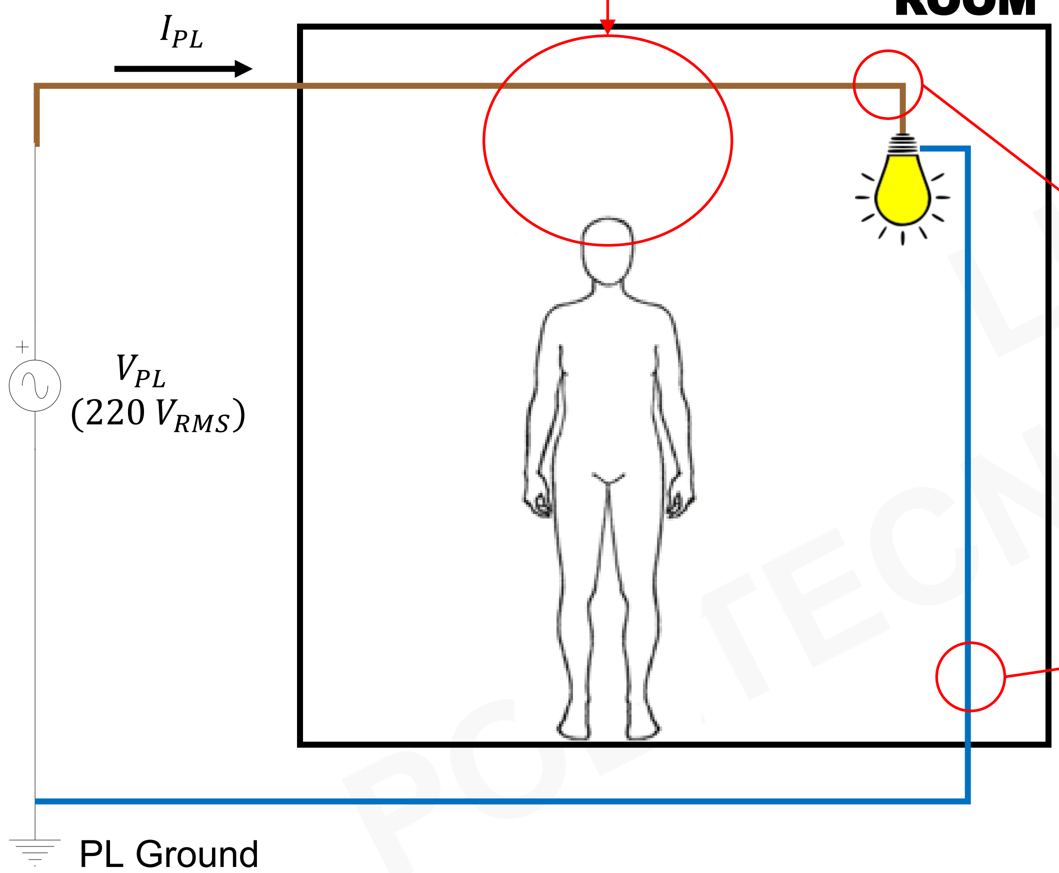
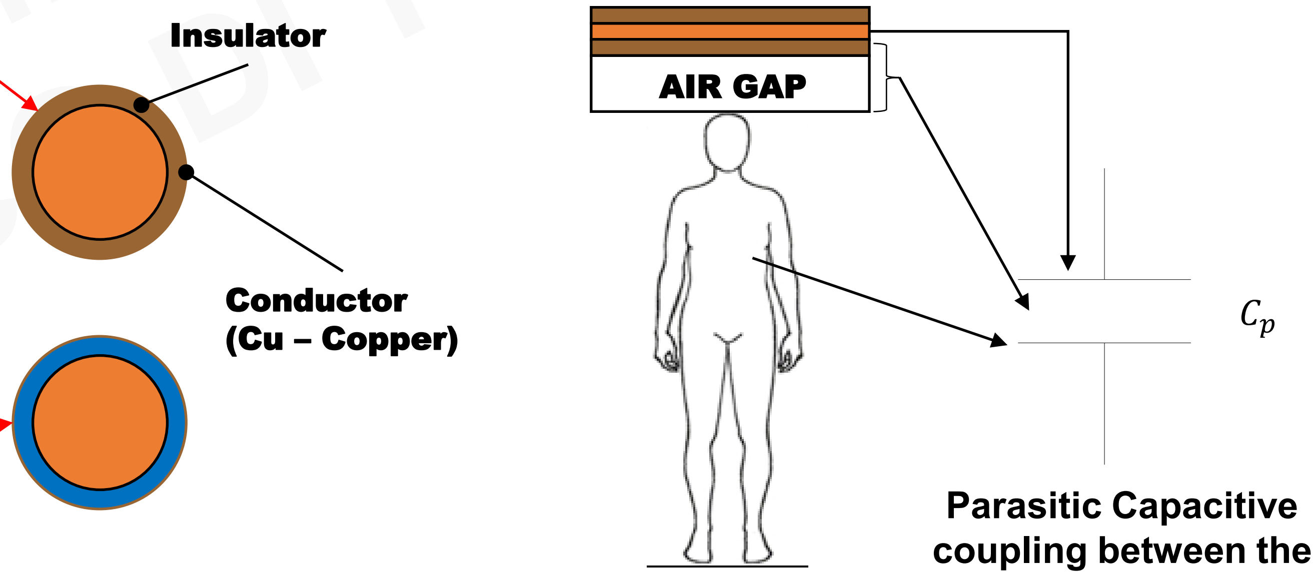
sEMG ACQUISITION: POWER LINE INTERFERENCE

Capacitive coupling between the subject and the power line mains



Q: Why is it important to model such a coupling?

Q: How can we electrically model the coupling between the subject and power supply mains?



Parasitic Capacitive coupling between the power supply mains and a subject

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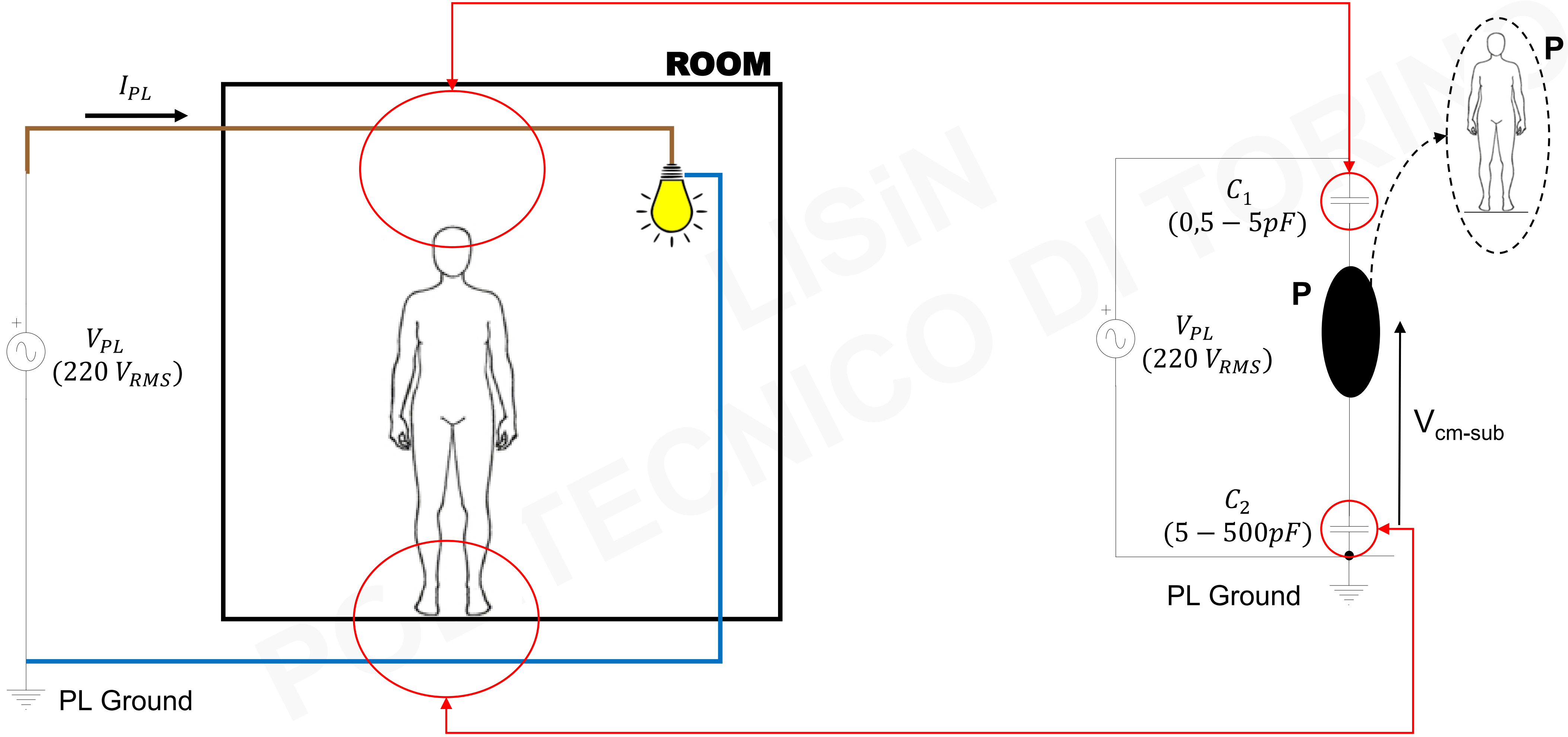
sEMG ACQUISITION: POWER LINE INTERFERENCE

Capacitive coupling between the subject and the power line mains



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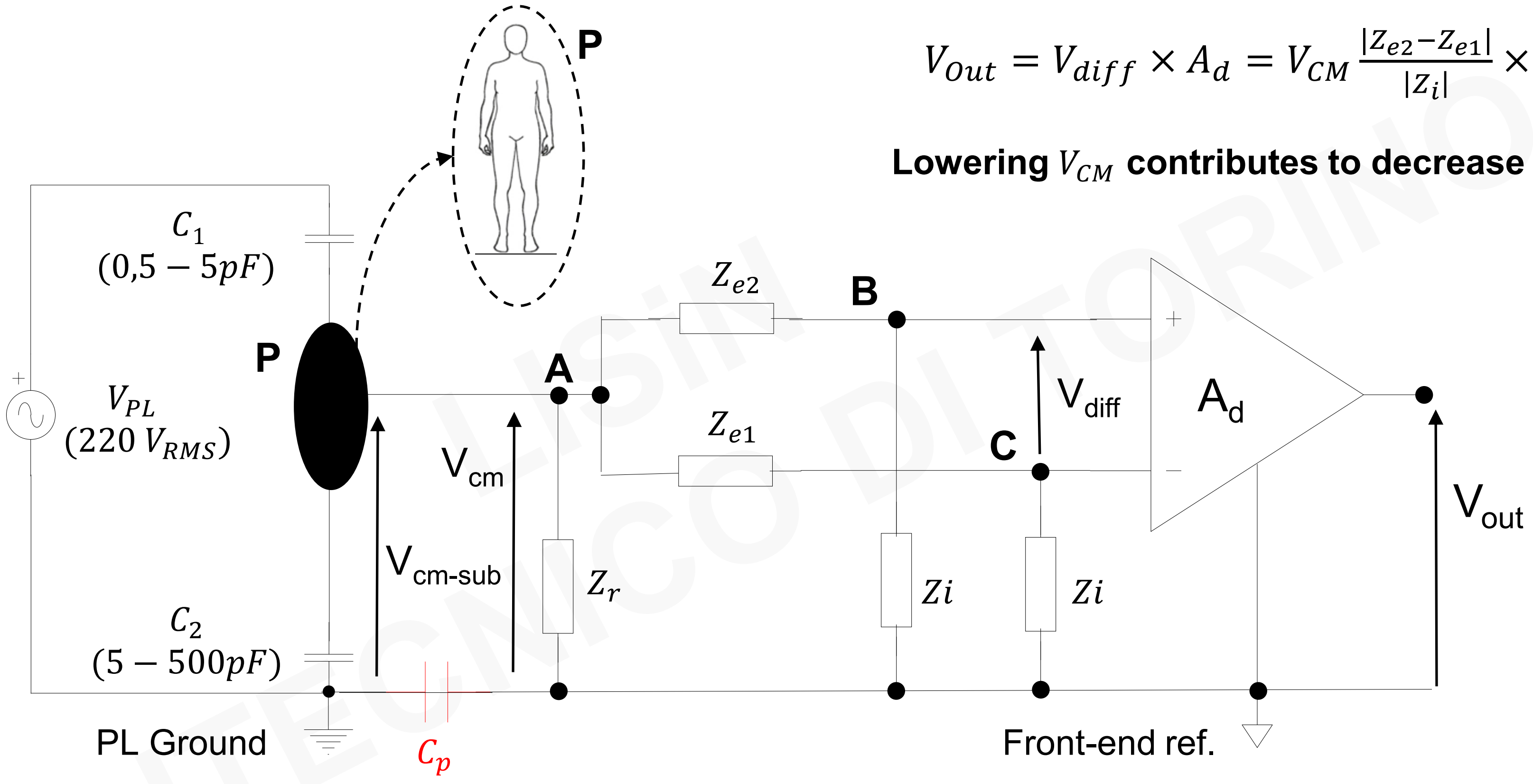
sEMG ACQUISITION: POWER LINE INTERFERENCE

$$V_{Out} = V_{diff} \times A_d = V_{CM} \frac{|Z_{e2} - Z_{e1}|}{|Z_i|} \times A_d$$

Lowering V_{CM} contributes to decrease PLI!!!



[Tutorial, Merletti and Cerone, JEK, 2020]

Using system having a floating reference w.r.t ground (e.g. battery powered wireless systems) helps reducing V_{CM}, thus reducing PLI

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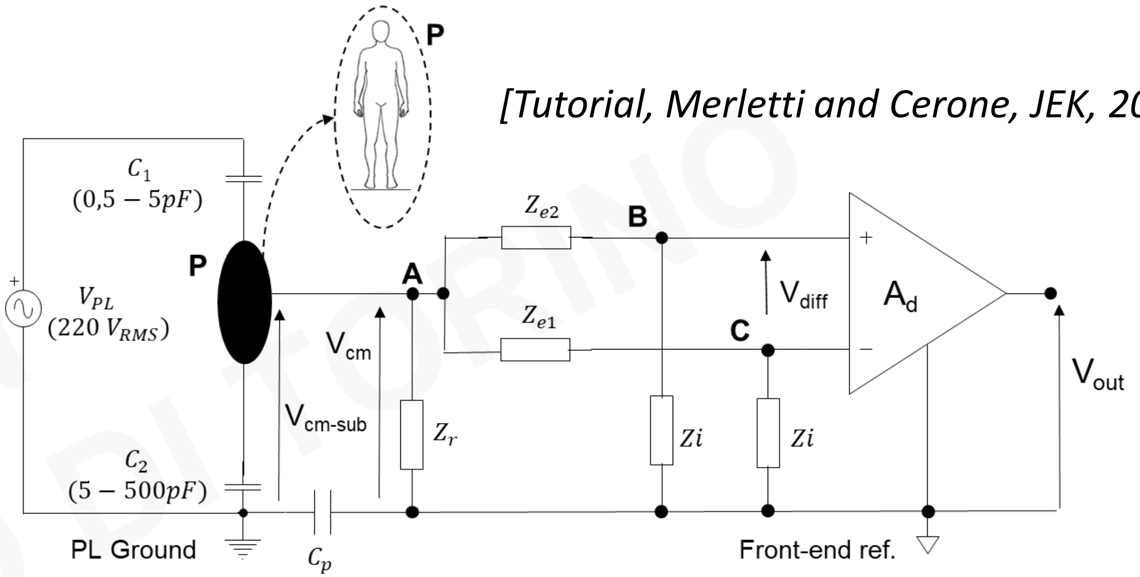
sEMG ACQUISITION: POWER LINE INTERFERENCE



If V_{CM} is still too high, it is possible to

- Lower $|Z_{e2} - Z_{e1}|$ (electrode-skin impedances unbalance)
- Use large reference electrodes to lower V_{CM}(not always possible due to system encumbrance)
- Increase Zi and CMRR (high costs, increased encumbrance)

$$V_{Out} = V_{CM}\frac{|Z_{e2}-Z_{e1}|}{|Z_i|} \times A_d$$

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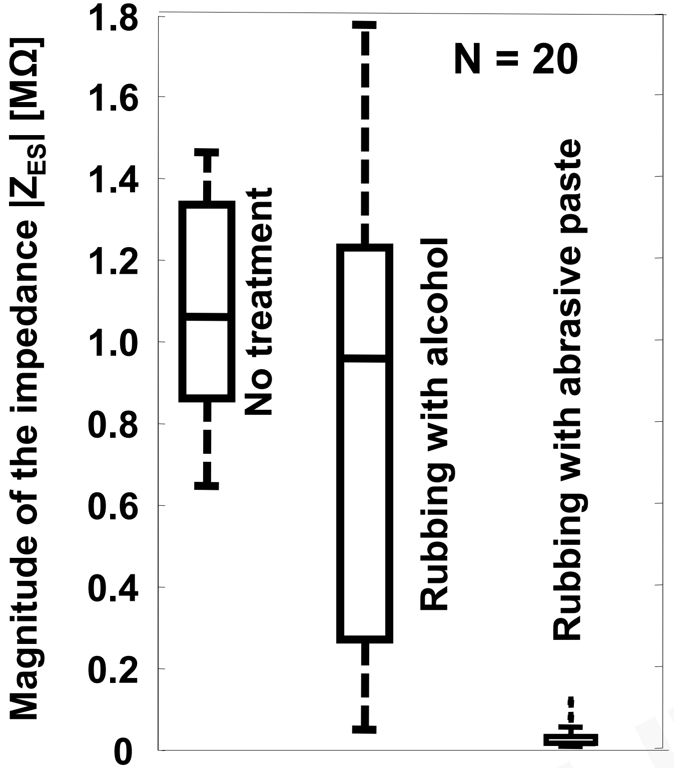
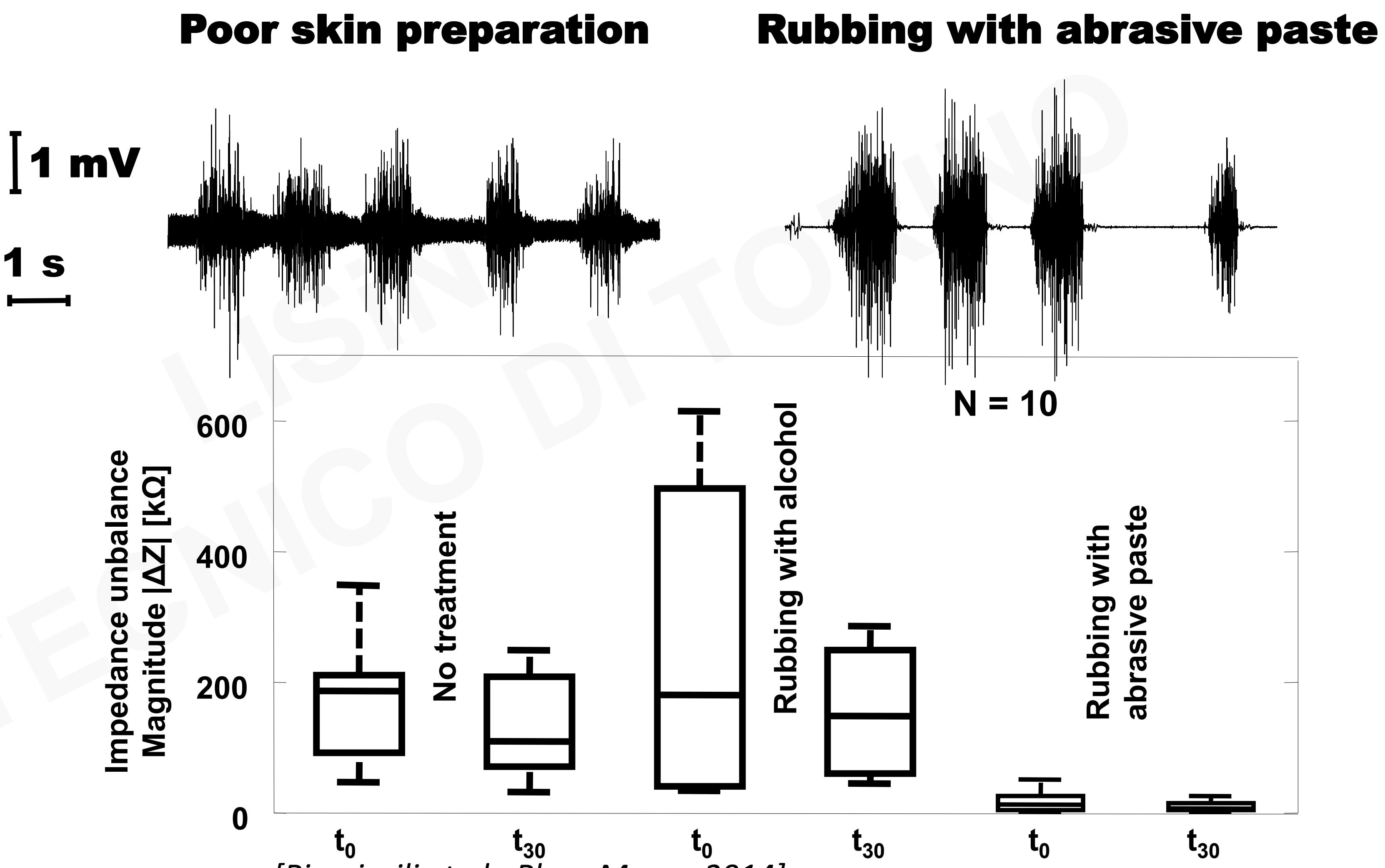
sEMG ACQUISITION: THE EFFECT OF SKIN PREPARATION ON Z_e



[Adapted from Piervirgili et al., Phys. Meas., 2014]



[Piervirgili et al., Phys. Meas., 2014]

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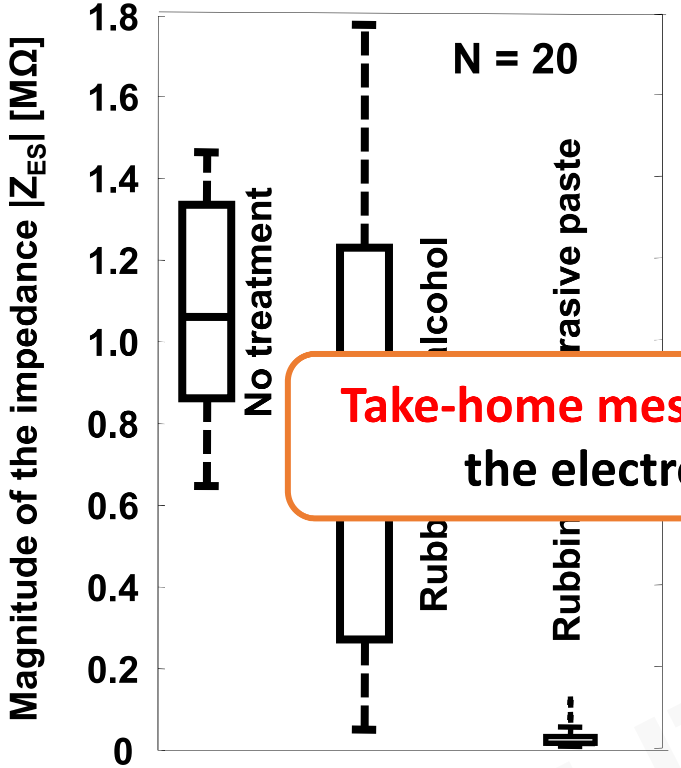
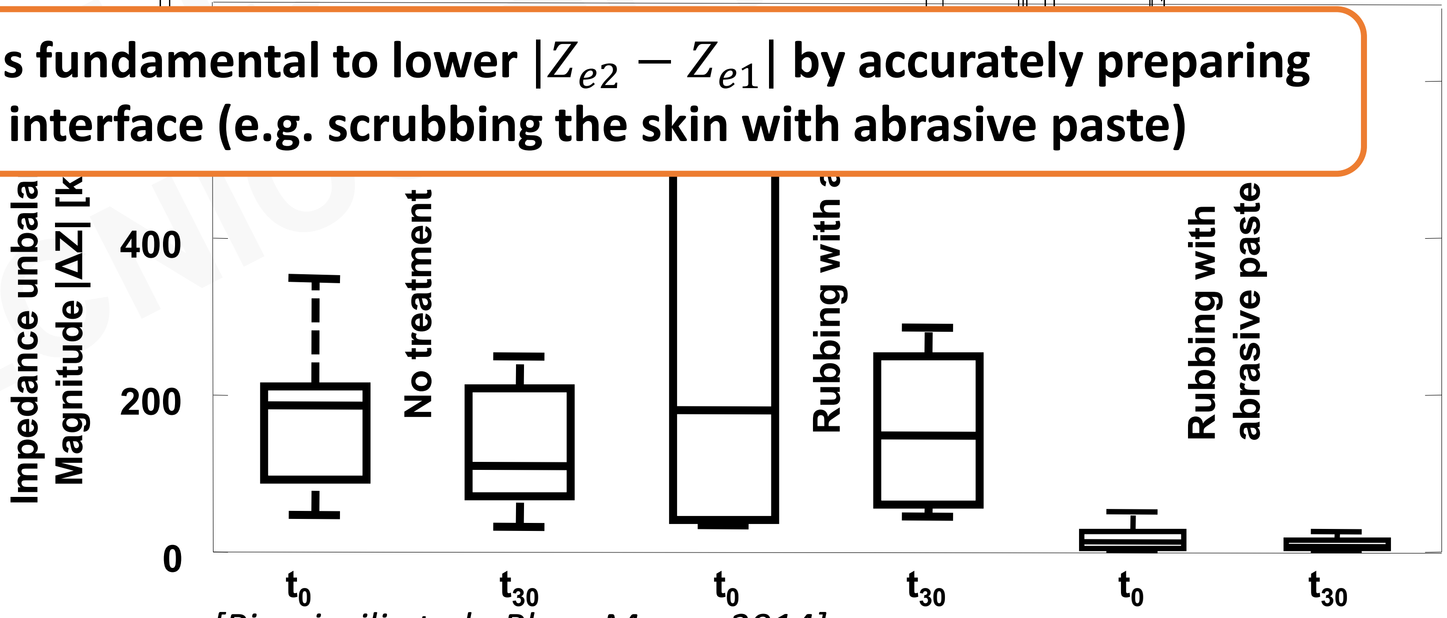
sEMG ACQUISITION: THE EFFECT OF SKIN PREPARATION ON Z_e



[Adapted from Piervirgili et al., Phys. Meas., 2014]

Poor skin preparation **Rubbing with abrasive paste**

Take-home message: It is fundamental to lower $|Z_{e2} - Z_{e1}|$ by accurately preparing the electrode-skin interface (e.g. scrubbing the skin with abrasive paste)



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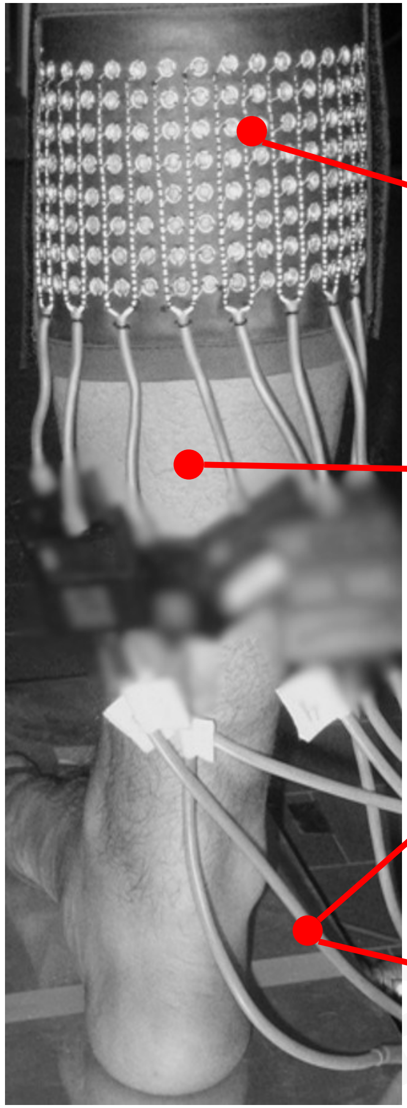
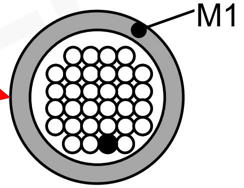
sEMG ACQUISITION: MOVEMENT ARTIFACTS



PROBLEM	CAUSE	SOLUTION
Skin-Electrodes Reciprocal movement	Electrode-Skin Impedance Changes	Use of Adhesive electrodes
Changes in terms of skin thickness	Electrode-Skin Half-Cell Potential(HCP) Changes	Electrode material (Low HCP) & setup preparation
Triboelectric effect due to the reciprocal movement of wires inside cables	Electrostatic charges distributed on the wires surface	Single wire cables or NO wires solutions



[Xiangxin Li et al., JEK, 2016]

[Cerone et al., IEEE TBME, 2019]

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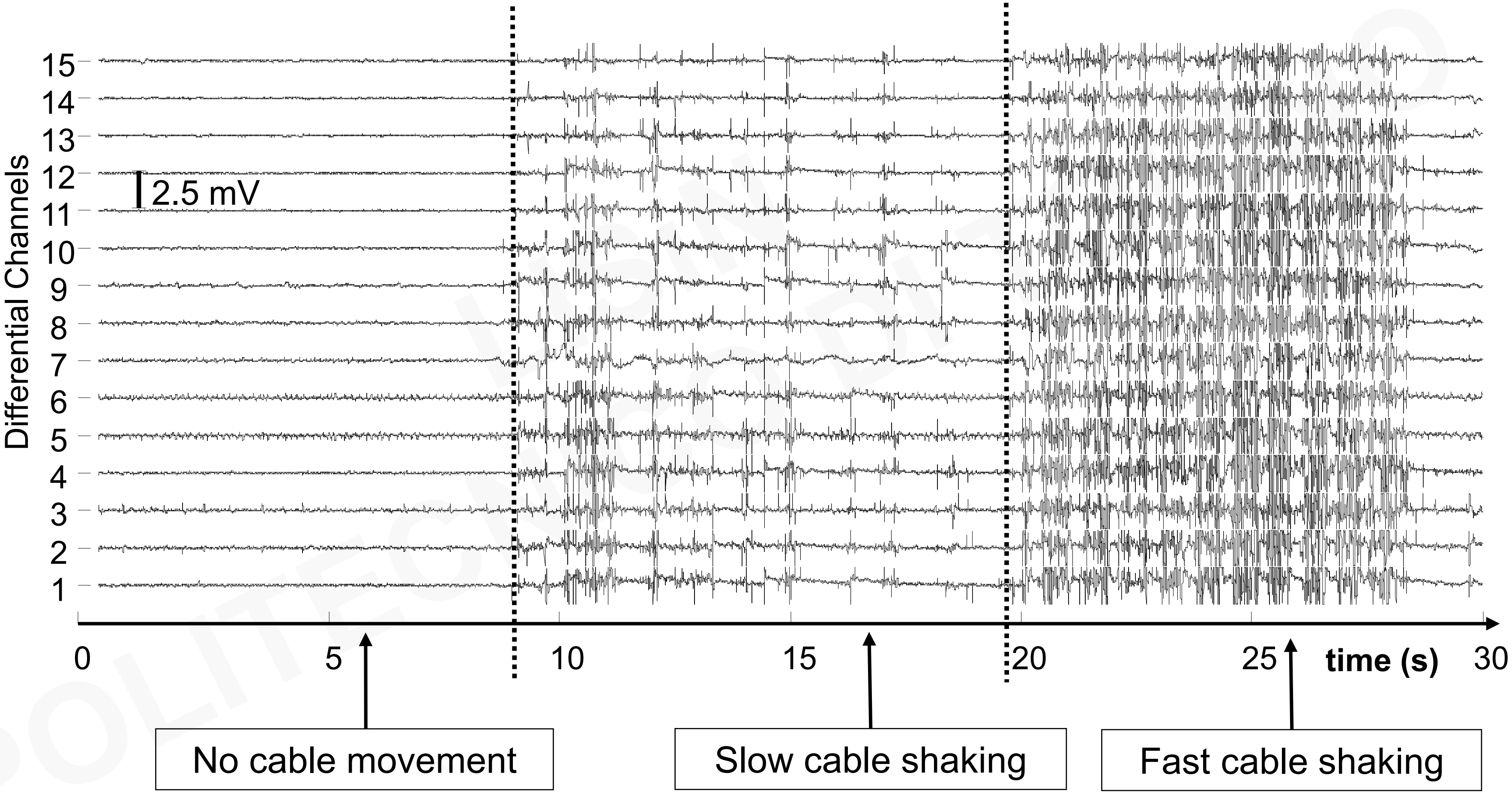
sEMG ACQUISITION: MOVEMENT ARTIFACTS

The effect of connecting cables



[Tutorial, Merletti and Cerone, JEK, 2020]

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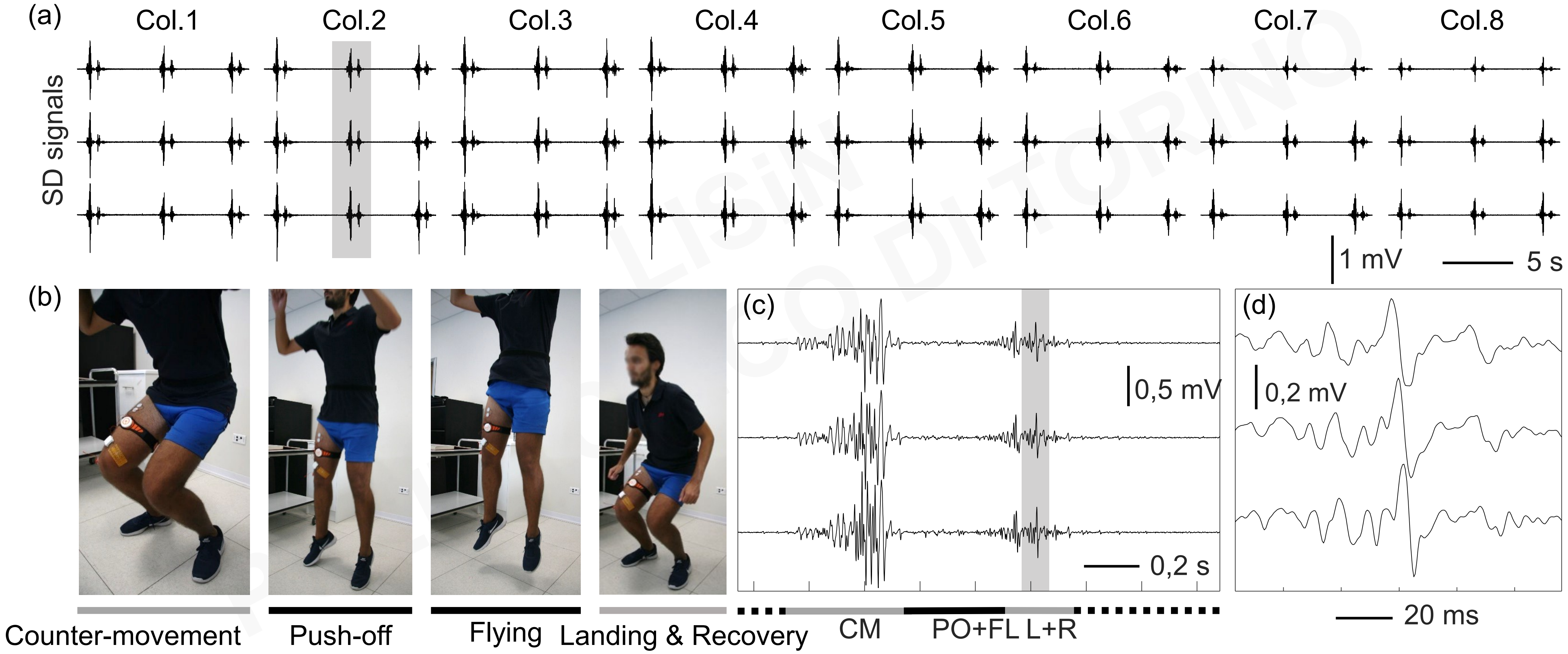
sEMG ACQUISITION: MOVEMENT ARTIFACTS

The effect of (avoiding) connecting cables

[Adapted from Cerone et al., IEEE TBME, 2019]



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sEMG ACQUISITION: MOVEMENT ARTIFACTS

The effect of (avoiding) connecting cables

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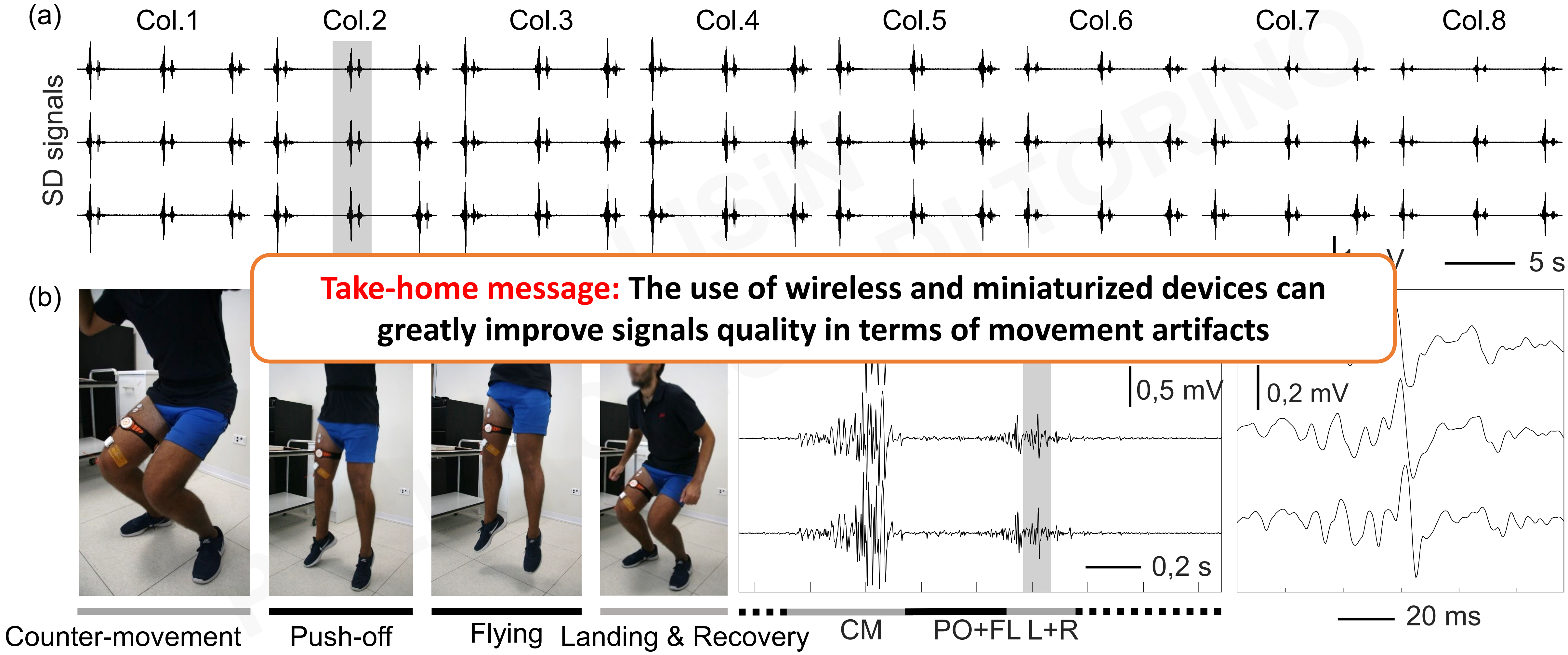

Take-home message: The use of wireless and miniaturized devices can greatly improve signals quality in terms of movement artifacts

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CONCLUSIONS

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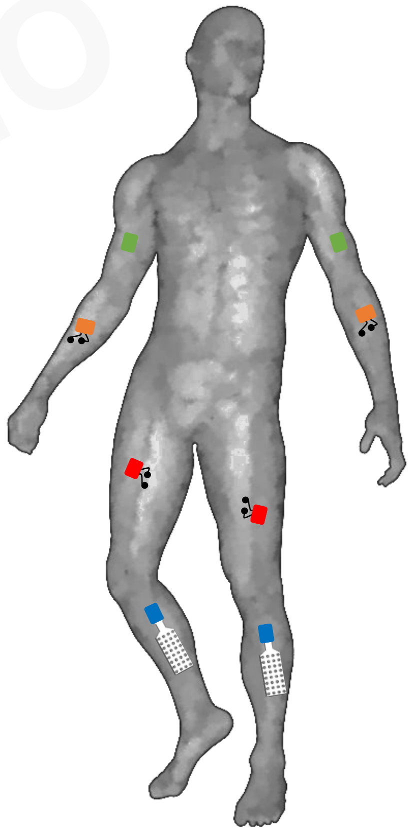
CONCLUSIONS

This presentation

- **Explained why having a basic background on technical problems related to the sEMG detection may be useful**
- **Described the main blocks constituting a device for sEMG signals detection and acquisition**
- **Discussed the most important issues and related best practices used to collect high quality sEMG signals**



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