INTRODUCTION TO SURFACE EMG DECOMPOSITION

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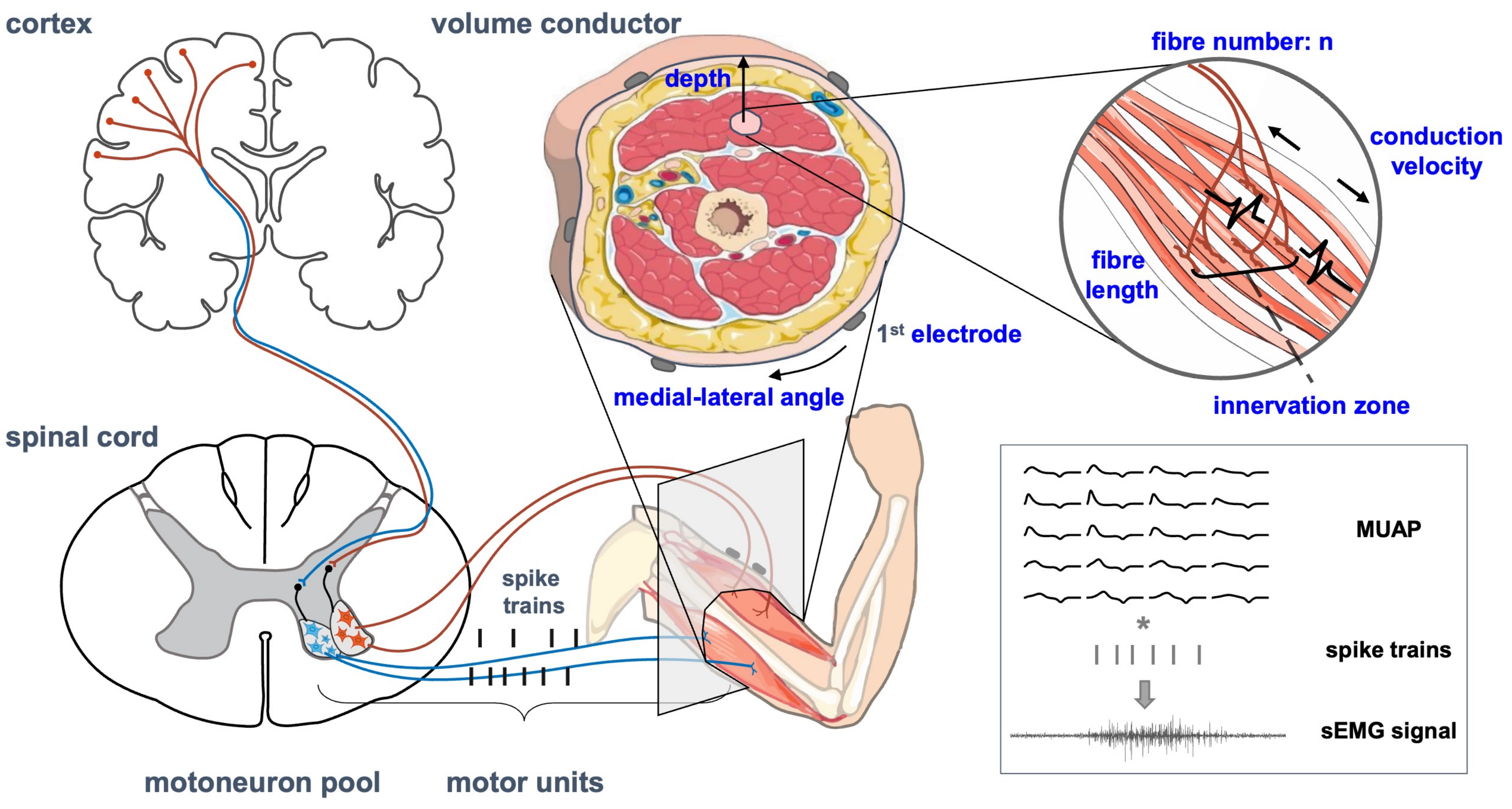
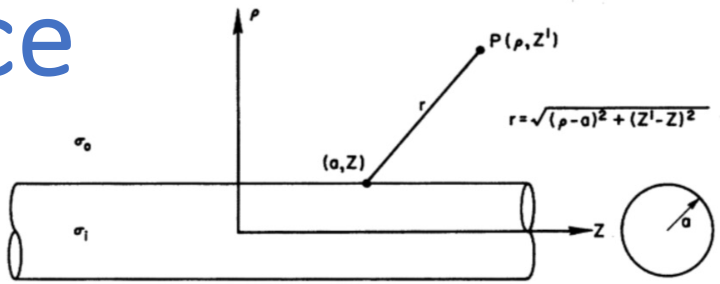
Material based on: Farina & Enoka, Evolution of surface electromyography: from muscle electrophysiology to neural recording and interfacing, JEK, 2023

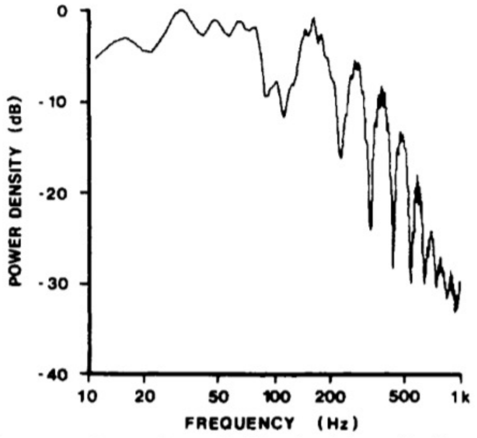
Physiology and biophysics of surface electromyography



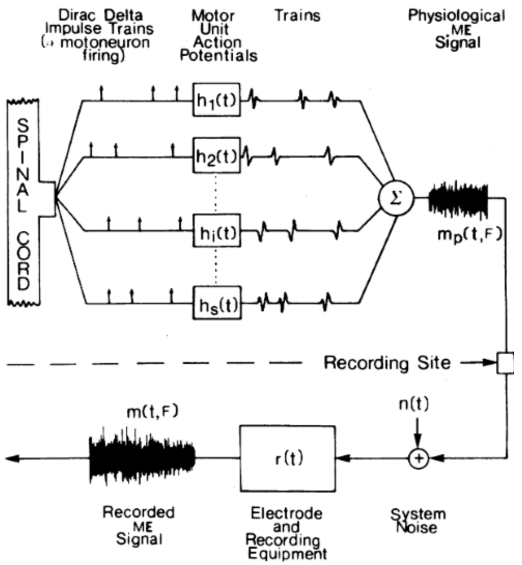
Shihan Ma, PhD Thesis, 2023



Plonsey *IEEE Trans Biomed Eng* 1974



Lindstrom & Magnusson *Proceedings of the IEEE* 1977



De Luca *IEEE Trans Biomed Eng* 1979

Problems in the interpretation of surface EMG

- Adrian ED. Interpretation of the electromyogram. *The Lancet* June 13: 1229-1233 and June 20: 1282-1286, 1925
- Pritchard EAB. The electromyogram of voluntary movements in man. *Brain* 53: 344-375, 1930
- Denny-Brown D. Interpretation of the electromyogram. *Archives of Neurology and Psychiatry* 61: 99-128, 1949
- Person RS. Problems in the interpretation of the electromyograms. *Biophysics* 8: 89-97, 302-307, 1963
- De Luca CJ. The use of surface electromyography in biomechanics. *J Appl Biomech* 13: 135-163, 1997

2004

The extraction of neural strategies from the surface EMG

Dario Farina,[1] Roberto Merletti,[1] and Roger M. Enoka[2]
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Farina, Dario, Roberto Merletti, and Roger M. Enoka. The extraction of neural strategies from the surface EMG. *J Appl Physiol* 96: 1486–1495, 2004; 10.1152/japplphysiol.01070.2003.—This brief review examines some of the methods used to infer central control strategies from surface electromyogram (EMG) recordings. Among the many uses of the surface EMG in studying the neural control of movement, the review critically evaluates only some of the applications. The focus is on the relations between global features of the surface EMG and the underlying physiological processes. Because direct measurements of motor unit activation are not available and many factors can influence the signal, these relations are frequently misinterpreted. These errors are compounded by the counterintuitive effects that some system parameters can have on the EMG signal. The phenomenon of crosstalk is used as an example of these problems. The review describes the limitations of techniques used to infer the level of muscle activation, the type of motor unit recruited, the upper limit of motor unit recruitment, the average discharge rate, and the degree of synchronization between motor units. Although the global surface EMG is a useful measure of muscle activation and assessment, there are limits to the information that can be extracted from this signal.

2014

The extraction of neural strategies from the surface EMG: an update

Dario Farina,[1] Roberto Merletti,[2] and Roger M. Enoka[3]
[1]*Department of Neurorehabilitation Engineering, Bernstein Focus Neurotechnology Göttingen, Bernstein Center for Computational Neuroscience, University Medical Center Göttingen, Georg-August University, Göttingen, Germany;* [2]*Laboratory for Engineering of the Neuromuscular System, Department of Electronics and Telecommunications, Politecnico di Torino, Turin, Italy; and* [3]*Department of Integrative Physiology, University of Colorado Boulder, Colorado*

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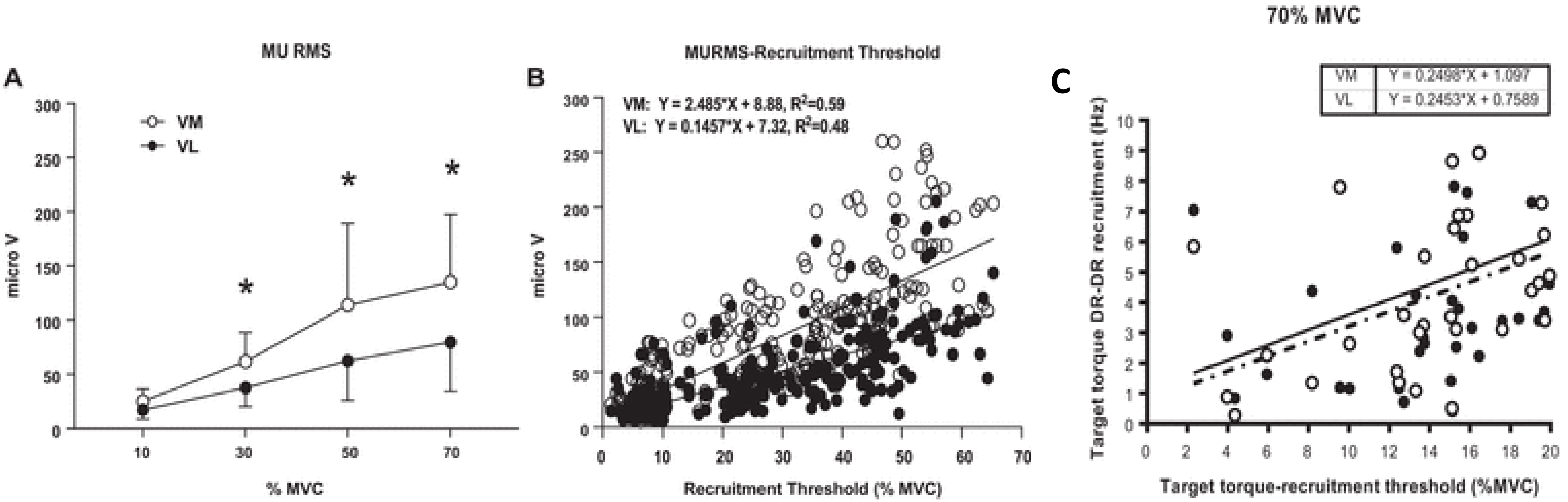
Farina D, Merletti R, Enoka RM. The extraction of neural strategies from the surface EMG: an update. *J Appl Physiol* 117: 1215–1230, 2014. First published October 2, 2014; doi:10.1152/japplphysiol.00162.2014.—A surface EMG signal represents the linear transformation of motor neuron discharge times by the compound action potentials of the innervated muscle fibers and is often used as a source of information about neural activation of muscle. However, retrieving the embedded neural code from a surface EMG signal is extremely challenging. Most studies use indirect approaches in which selected features of the signal are interpreted as indicating certain characteristics of the neural code. These indirect associations are constrained by limitations that have been detailed previously (Farina D, Merletti R, Enoka RM. *J Appl Physiol* 96: 1486–1495, 2004) and are generally difficult to overcome. In an update on these issues, the current review extends the discussion to EMG-based coherence methods for assessing neural connectivity. We focus first on EMG amplitude cancellation, which intrinsically limits the association between EMG amplitude and the intensity of the neural activation and then discuss the limitations of coherence methods (EEG-EMG, EMG-EMG) as a way to assess the strength of the transmission of synaptic inputs into trains of motor unit action potentials. The debated influence of rectification on EMG spectral analysis and coherence measures is also discussed. Alternatively, there have been a number of attempts to identify the neural information directly by decomposing surface EMG signals into the discharge times of motor unit action potentials. The application of this approach is extremely powerful, but validation remains a central issue.

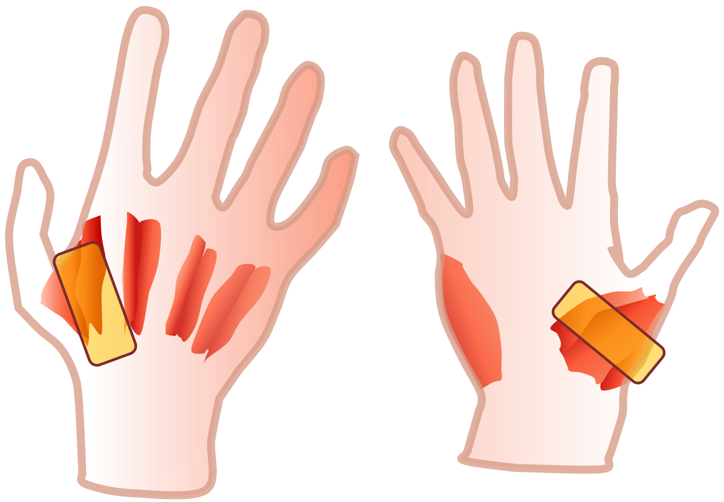
2024 edition coming soon ……

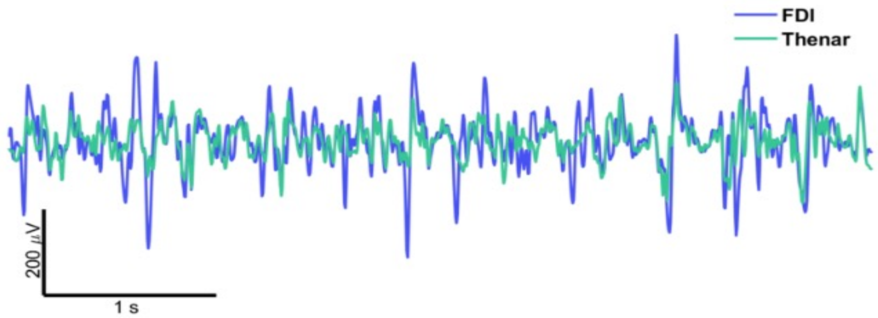
Example: Surface EMG amplitude and neural drive

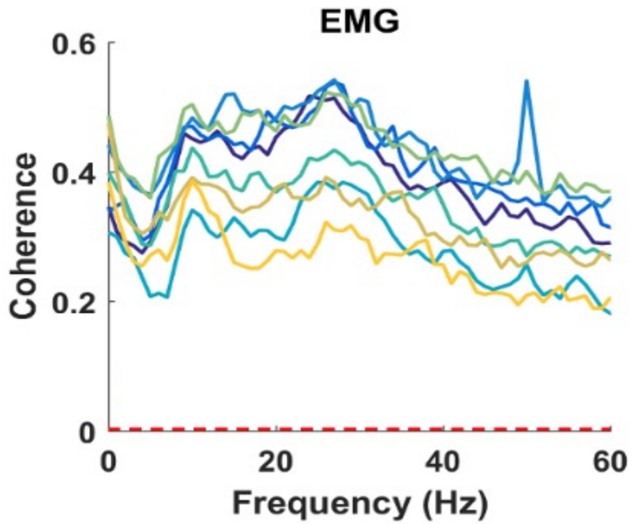


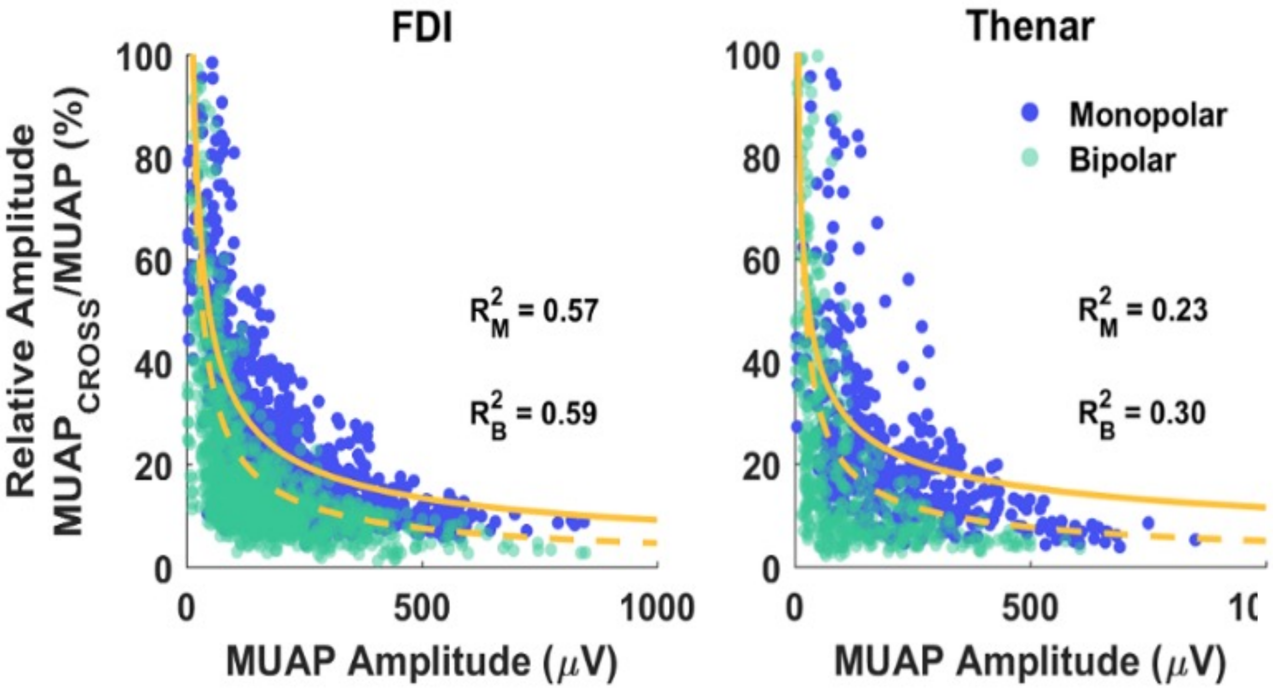
Martinez-Valdes et al. *J Appl Physiol* 2018

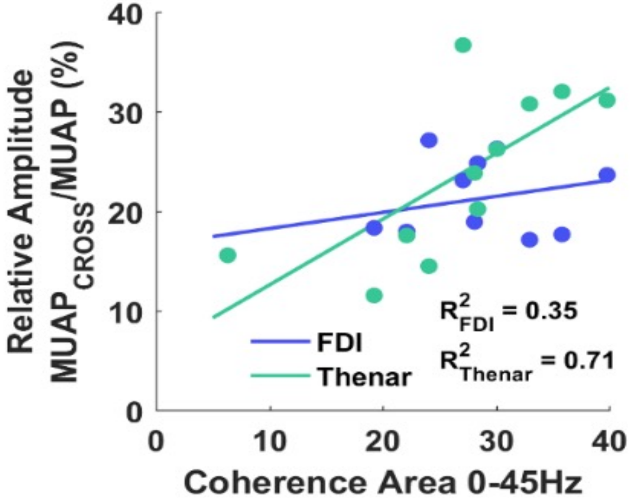
Example: Crosstalk







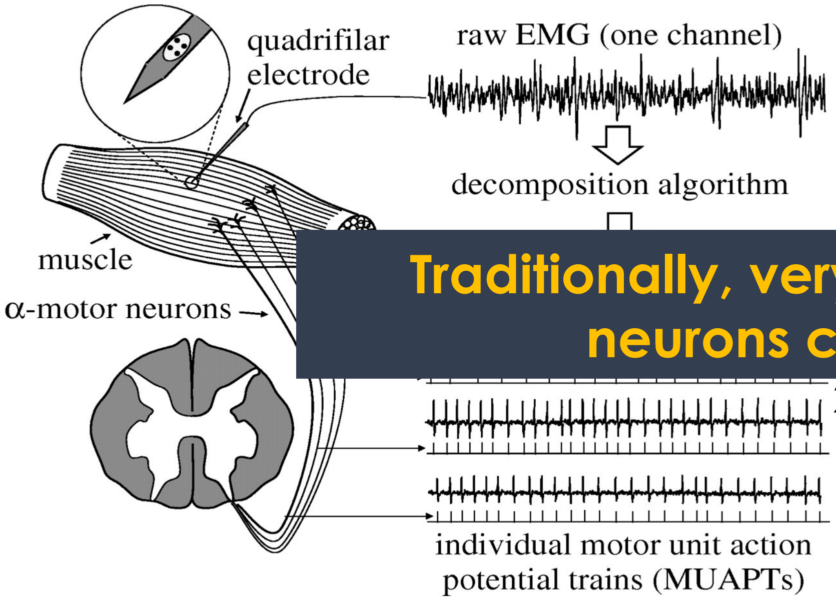


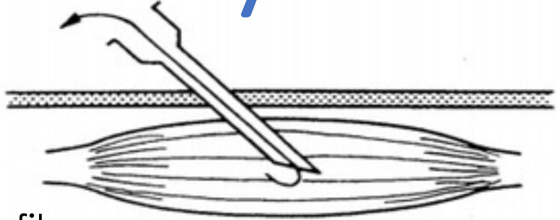


Del Vecchio et al. *J Physiol* 2019

Direct probing of neural activity

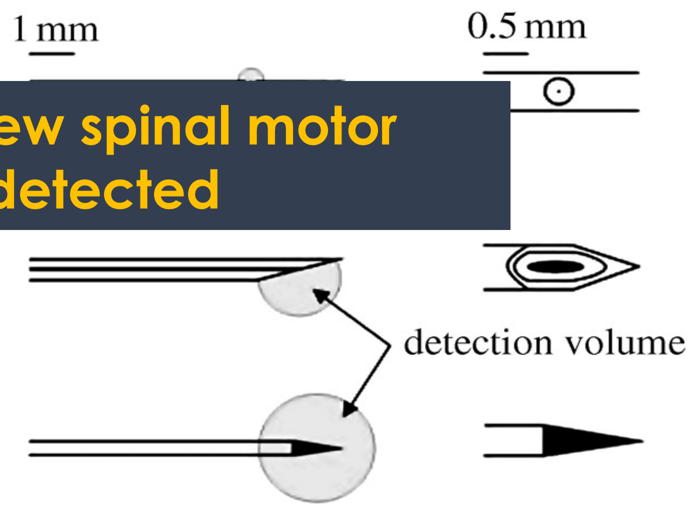
Quadrifilar electrode (*De Luca* 1972)





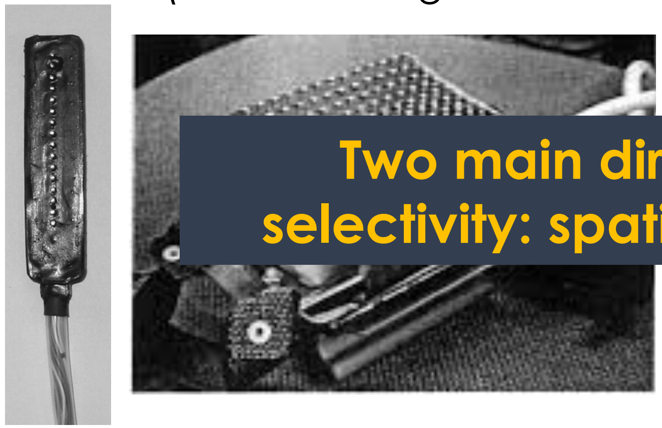
Wire electrodes (*Basmajian*)

Single fiber, concentric monopolar (Adrian & Bronk, 1929) (modified from Ekstedt & Stålberd, *Comput Programs Biomed.*, 1973)



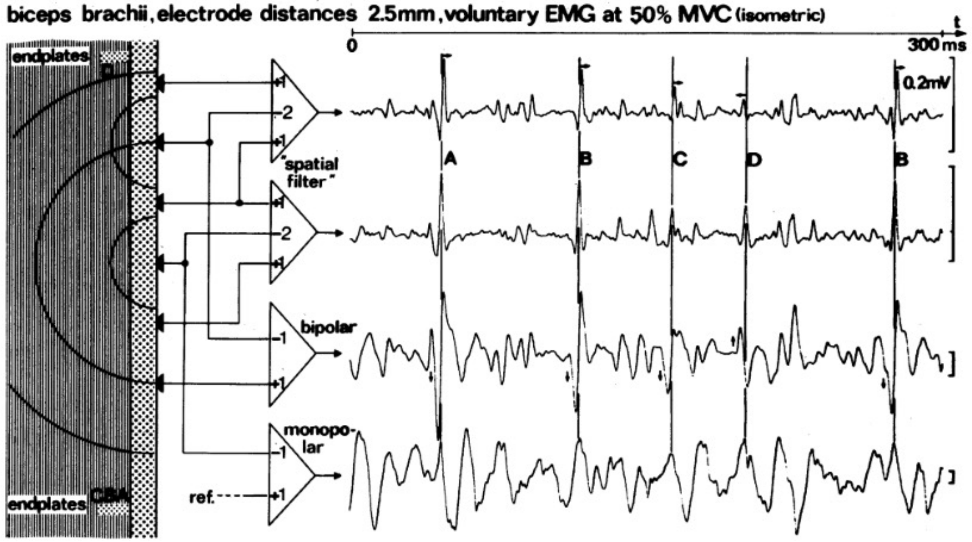
Traditionally, very selective, few spinal motor neurons concurrently detected

Non-invasive linear and bidimensional arrays, with spatial filtering for single motor unit identification (*Masuda, Stegeman, Merletti, Rau, Disselhorst-Klug, Farina, De Luca*)

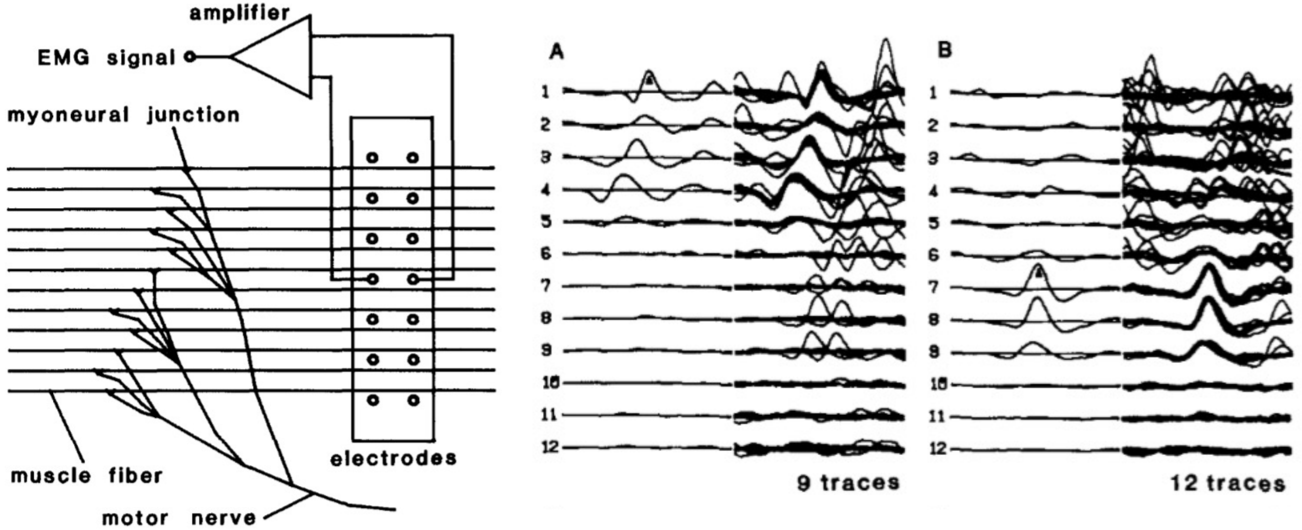


Two main directions to overcome the low selectivity: spatial sampling and spatial filtering

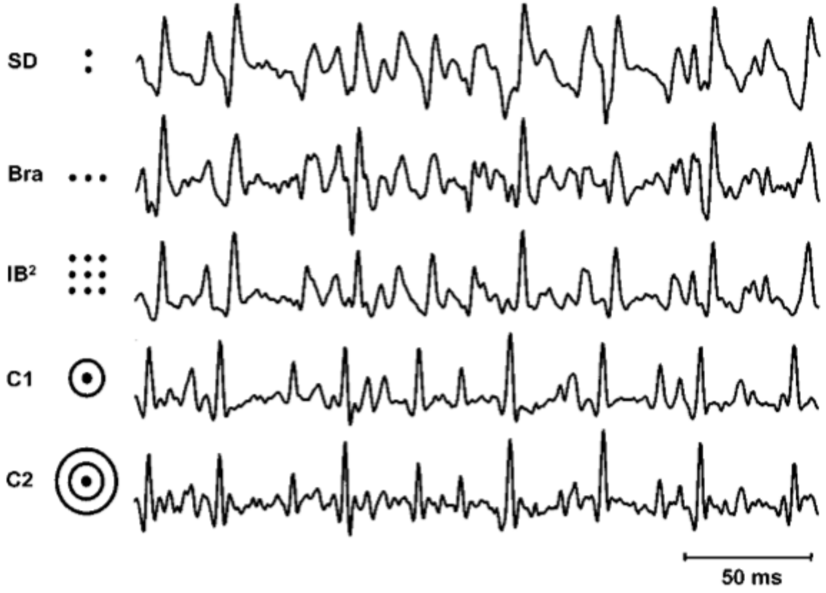
Surface EMG and motor unit signatures



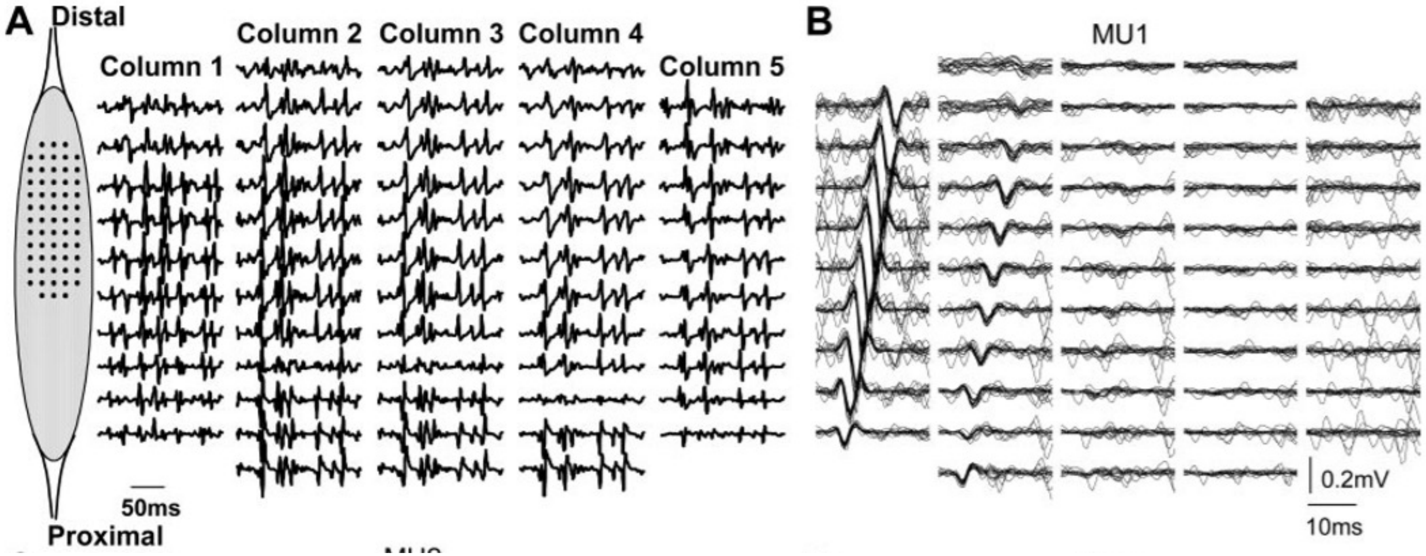
Reucher et al. *IEEE Trans Biomed Eng* 1987



Masuda et al. *Electroenc Clin Neurophysiol* 1985

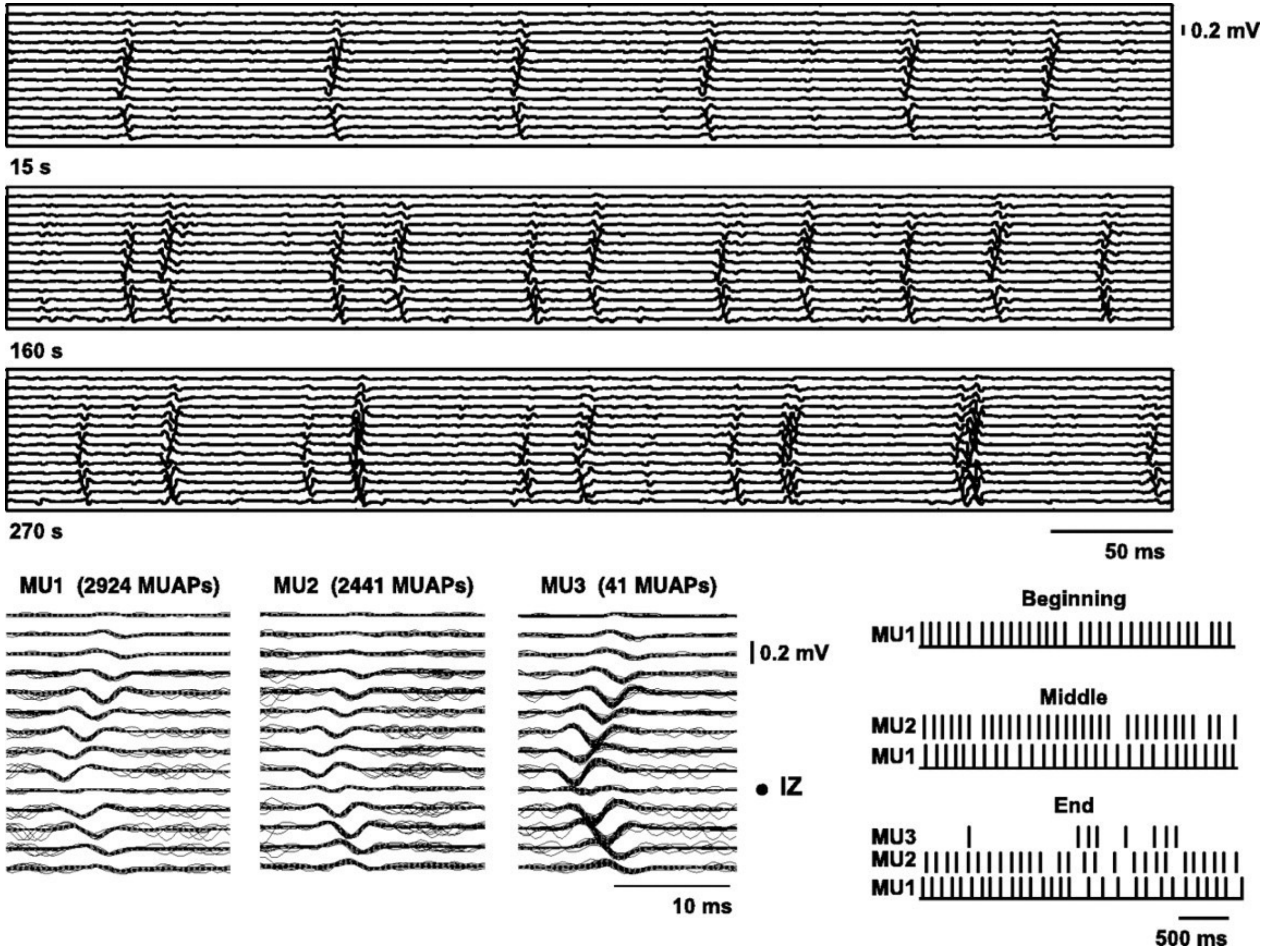


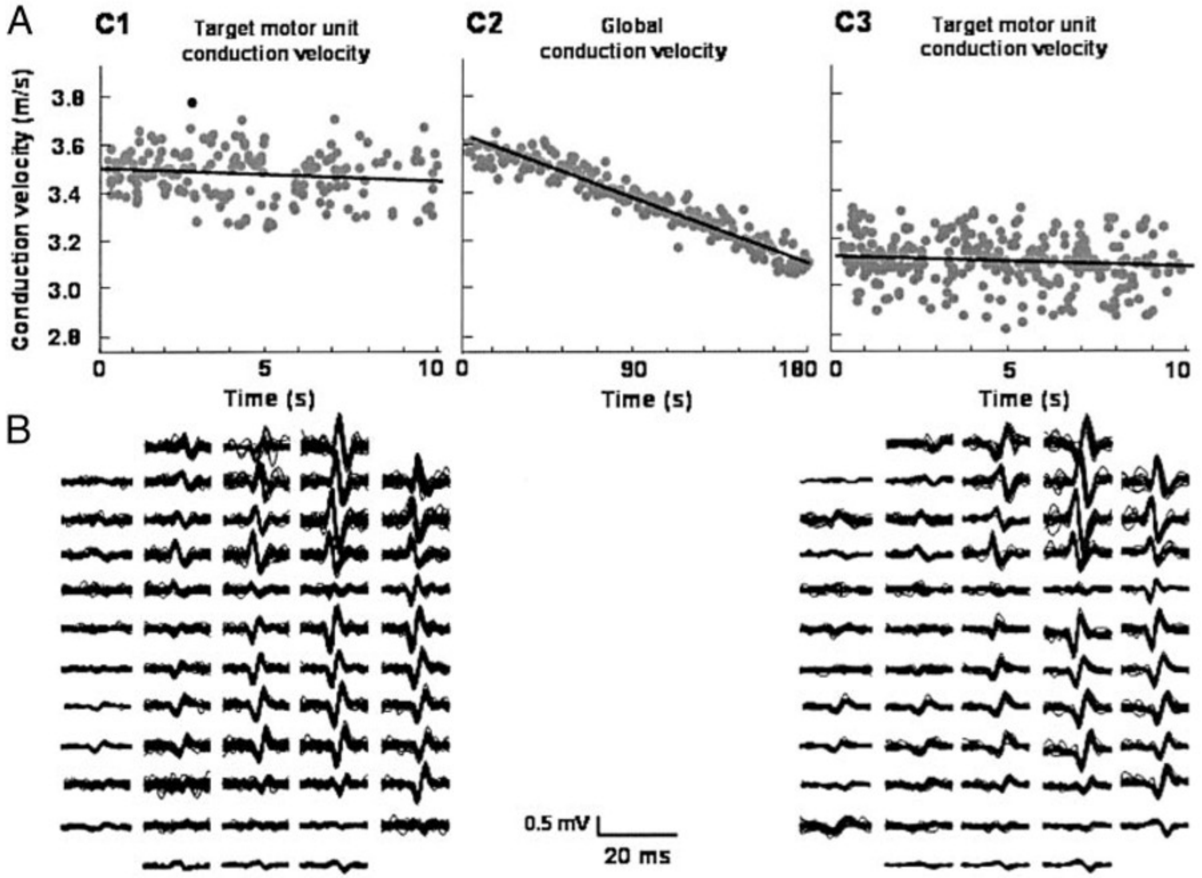
Farina & Cescon IEEE Trans Biomed Eng 2001



Merletti et al. *Electroenc Clin Neurophysiol* 1999; Farina et al. *J Appl Physiol* 2004; Kleine et al. *J Electromyogr Kinesiol* 2007

Volitional control of motor units with surface EMG feedback

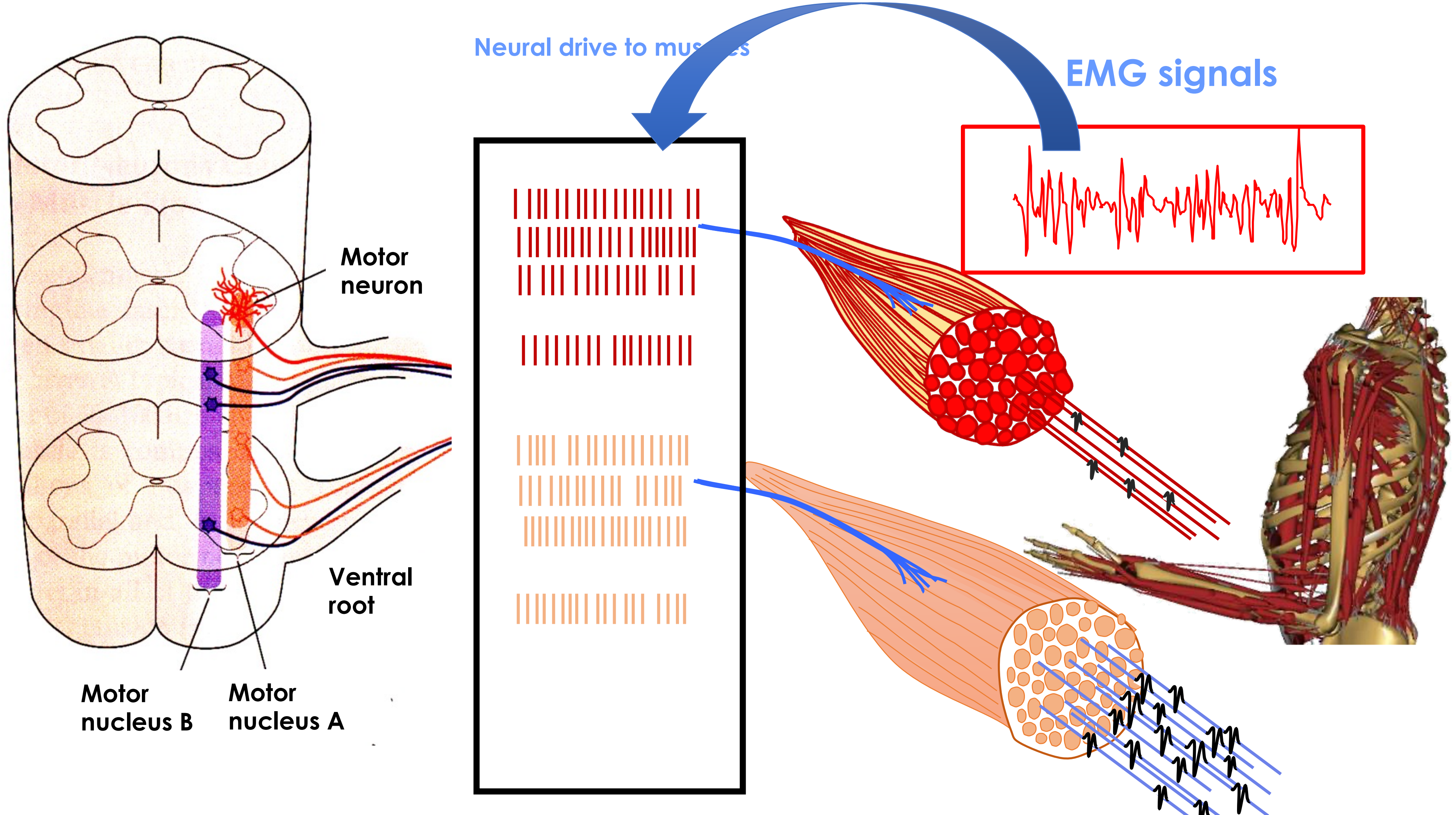




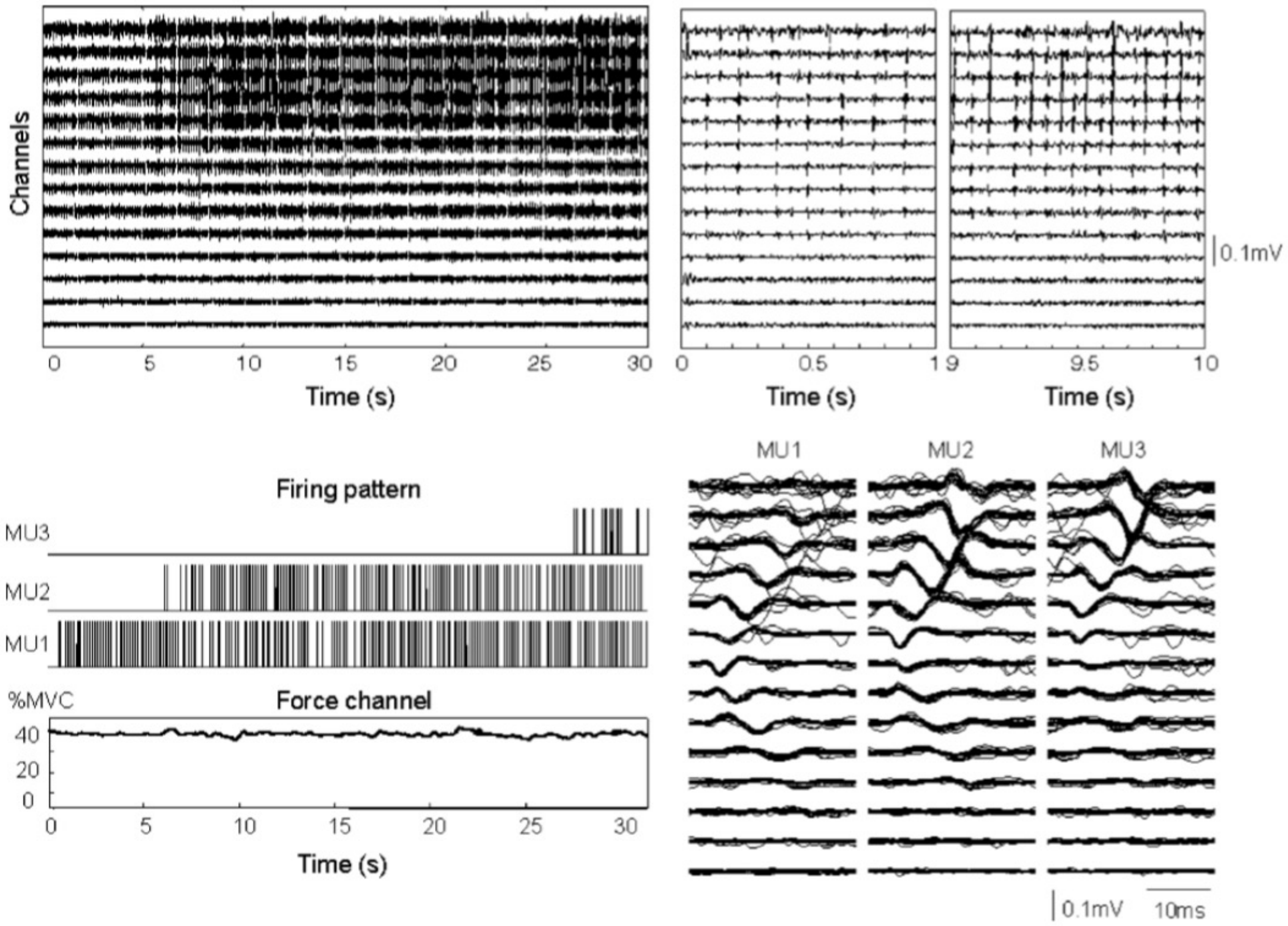
Gazzoni et al. *Acta Physiol Pharmacol Bulg.* 2001; Merletti et al. *J Electromyogr Kinesiol.* 2003; Farina et al. *J Appl. Physiol.* 2004, 2005; Gazzoni et al. *J Neurophysiol* 2005

Estimating the neural drive to muscles

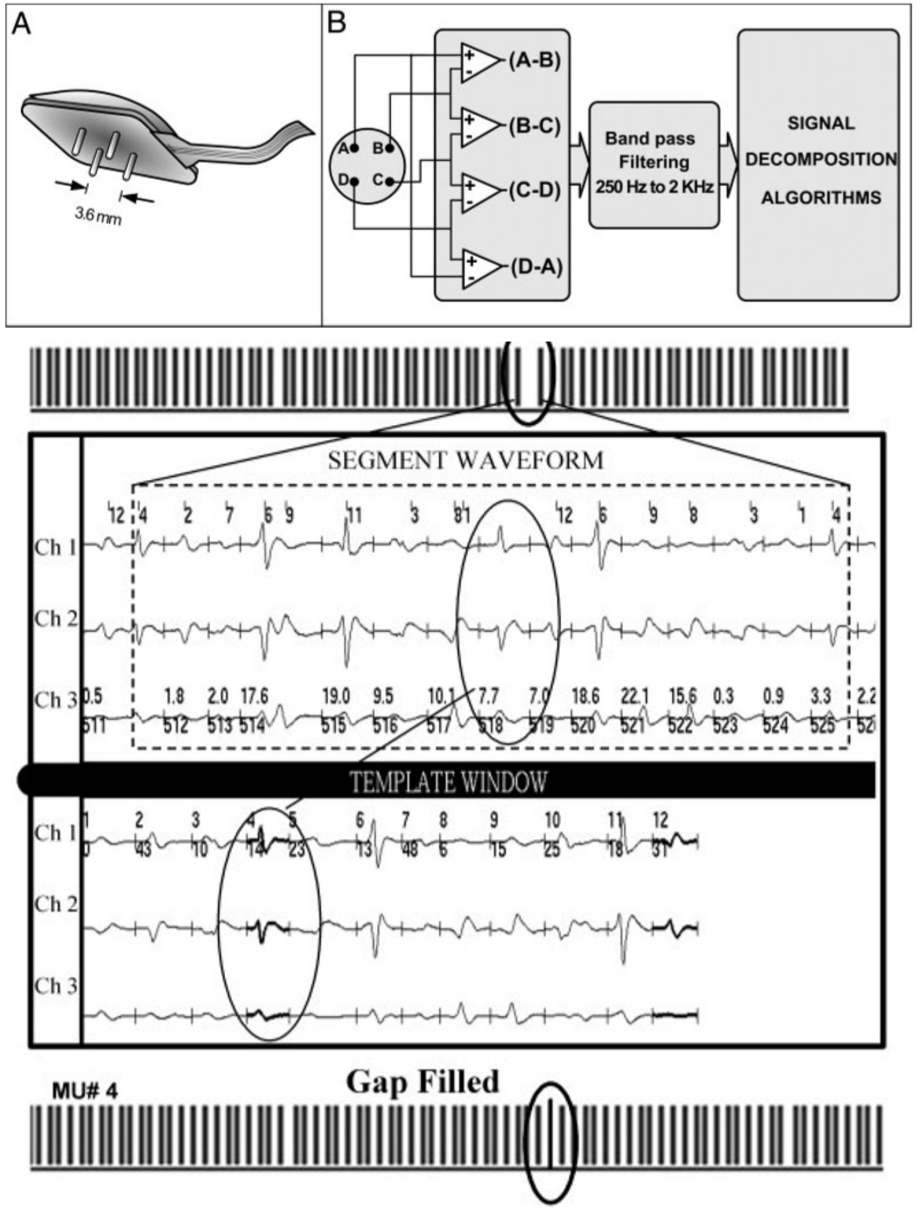
Achieving a representative estimate of the neural drive to muscle implies full decomposition of the signal with a level of accuracy comparable with that of intramuscular recordings



Decomposition with spike sorting methods



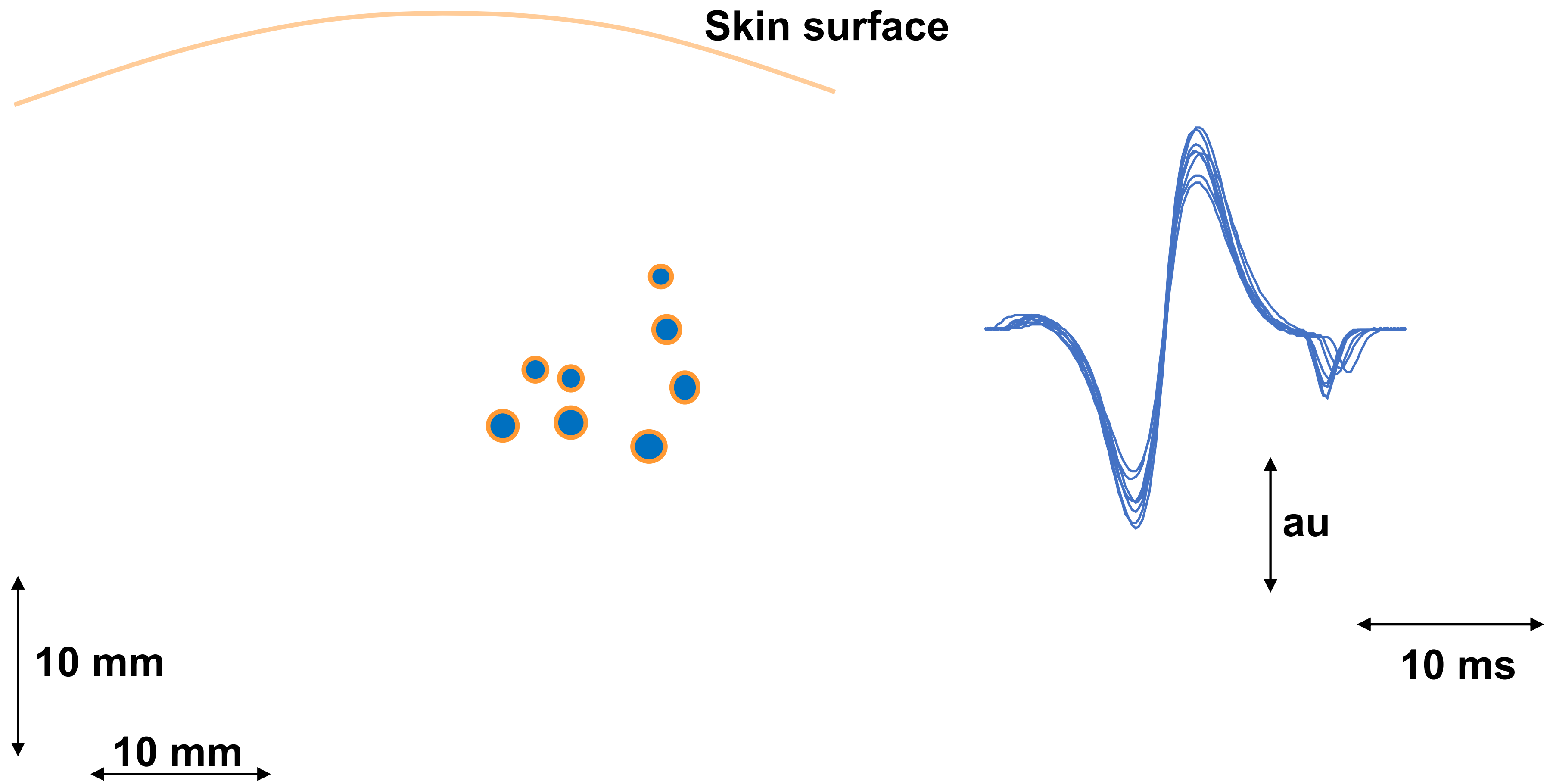
Gazzoni et al. *J Neurosci Meth* 2004



De Luca et al. *J Neurophysiol* 2006

Challenges in surface EMG spike sorting

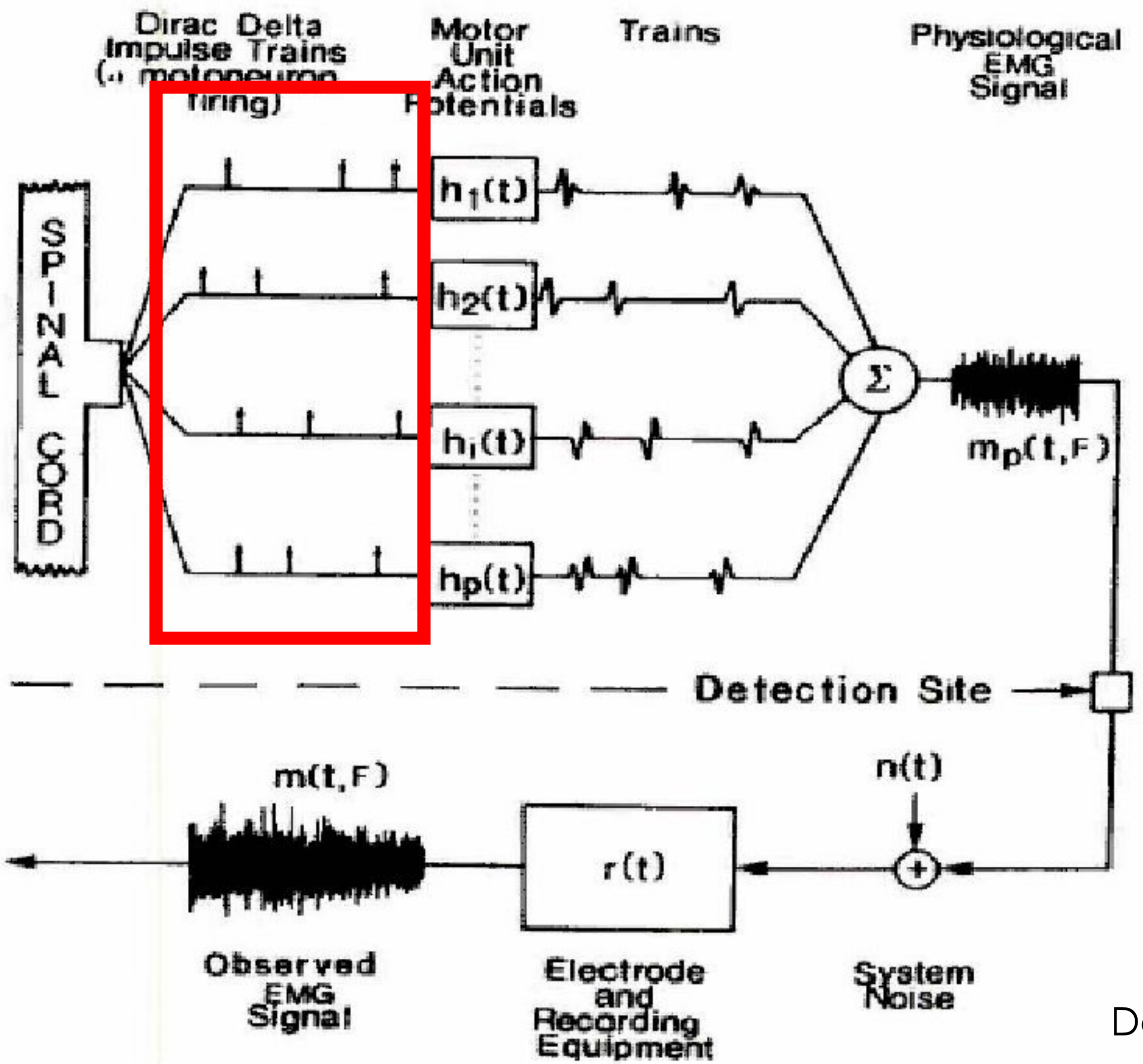
The volume conductor reduces the differences between motor unit action potential waveforms



Farina et al. *J Neurophysiol.* 2008

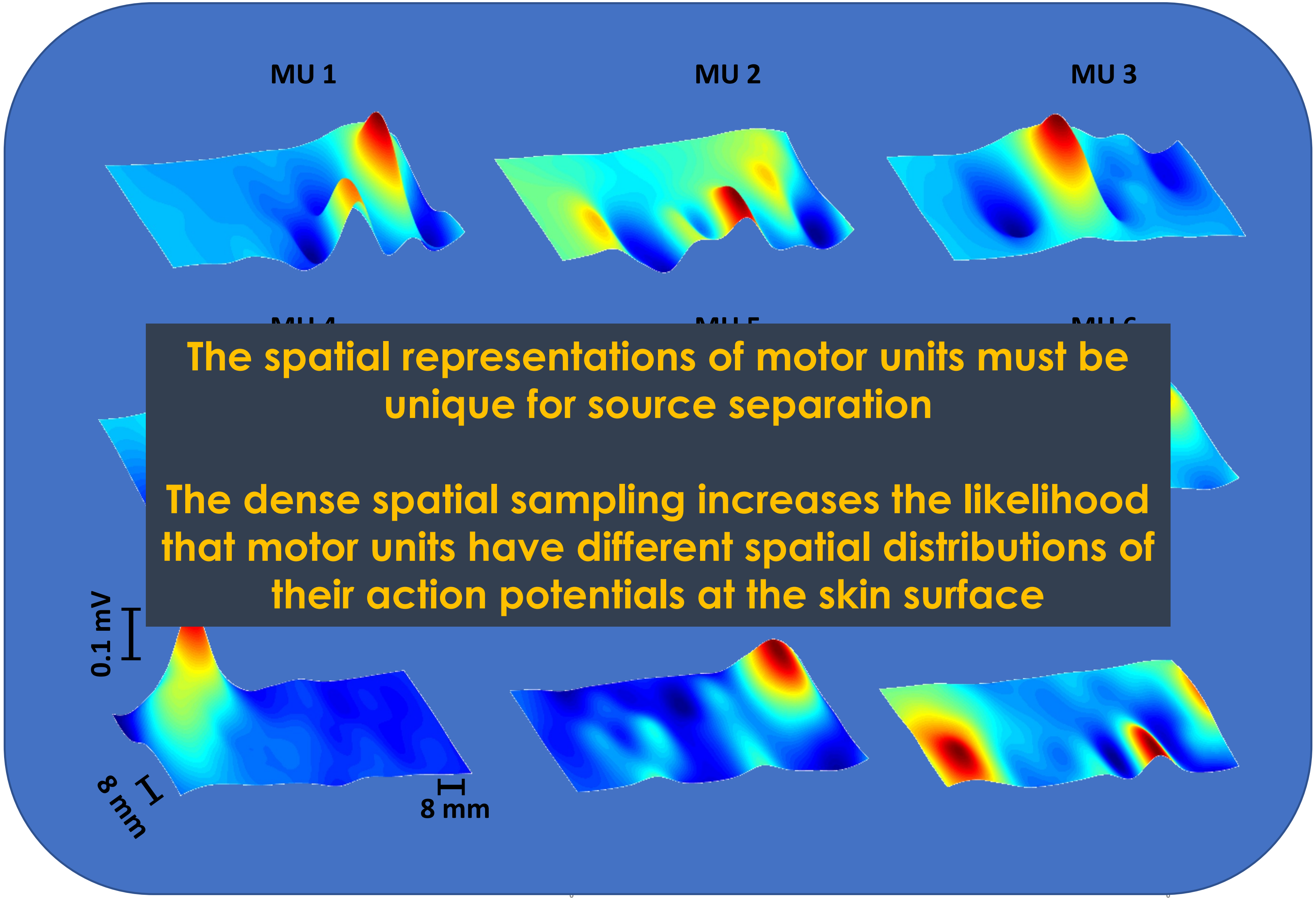
Inverse problem

$$x_i(k) = \sum_{j=1}^{n} \sum_{l=0}^{L-1} h_{ij}(l) \sum_{r} \delta(k - \varphi_{jr} - l) + n_i(k),$$



De Luca *IEEE Trans Biomed Eng* 1979

High spatial sampling approach

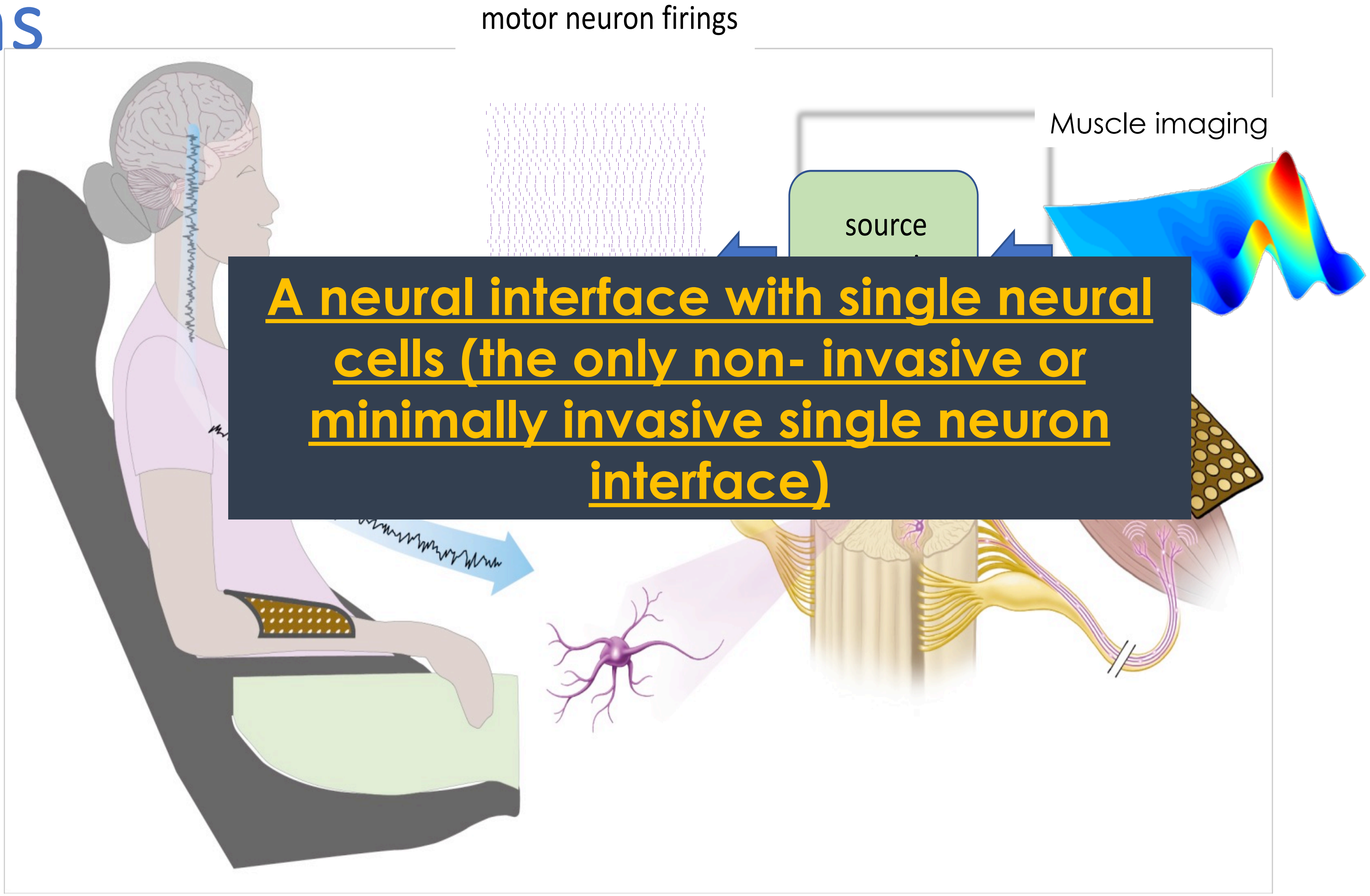


The spatial representations of motor units must be unique for source separation

The dense spatial sampling increases the likelihood that motor units have different spatial distributions of their action potentials at the skin surface

Farina et al. *J Neurophysiol* 2008

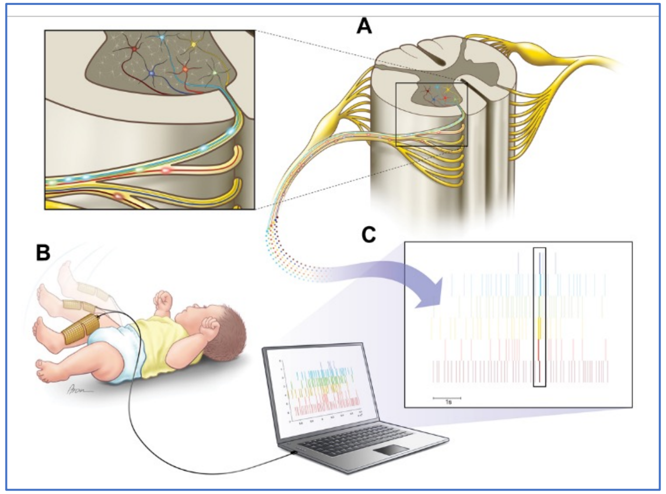
Sampling large populations of motor neurons

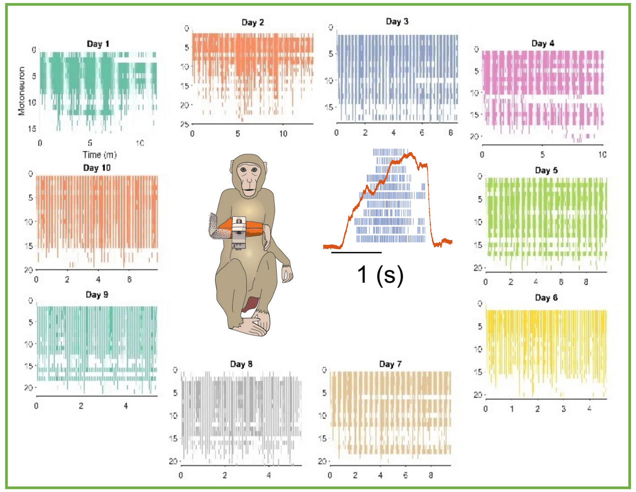


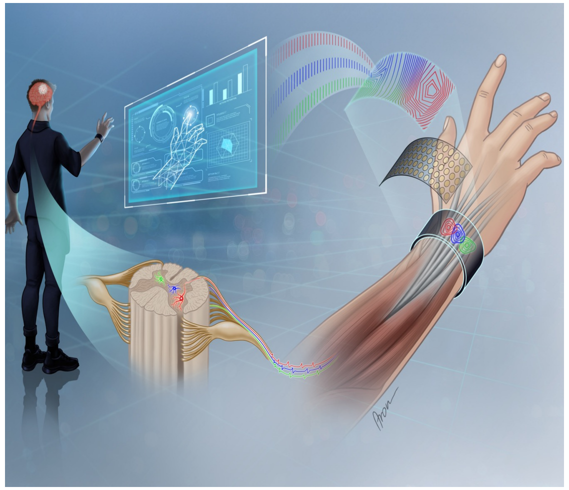
A neural interface with single neural cells (the only non- invasive or minimally invasive single neuron interface)

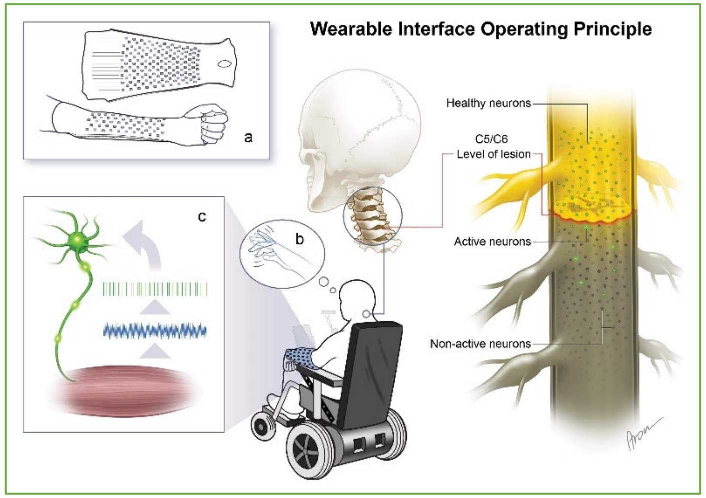
Holobar & Farina *IEEE Signal Proc Magazine* 2021

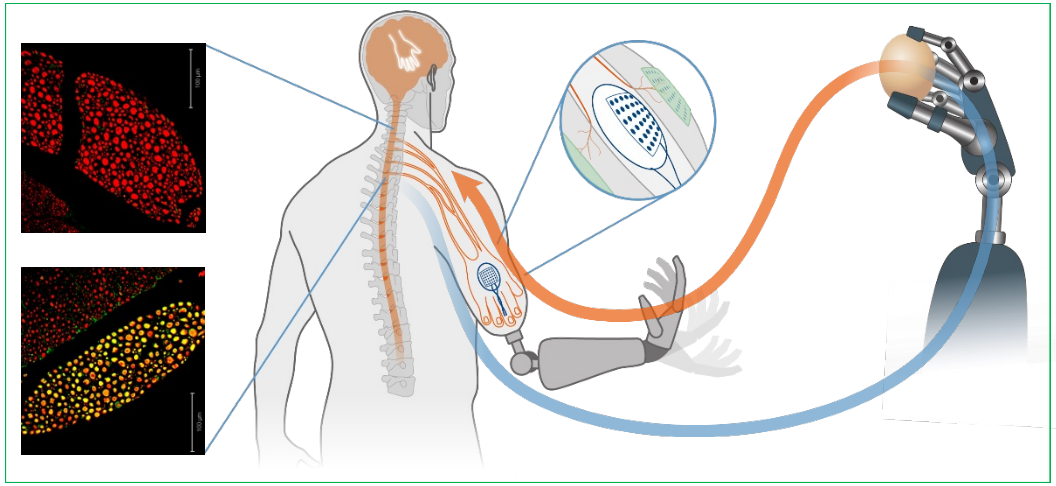
Potential applications in neural interfacing





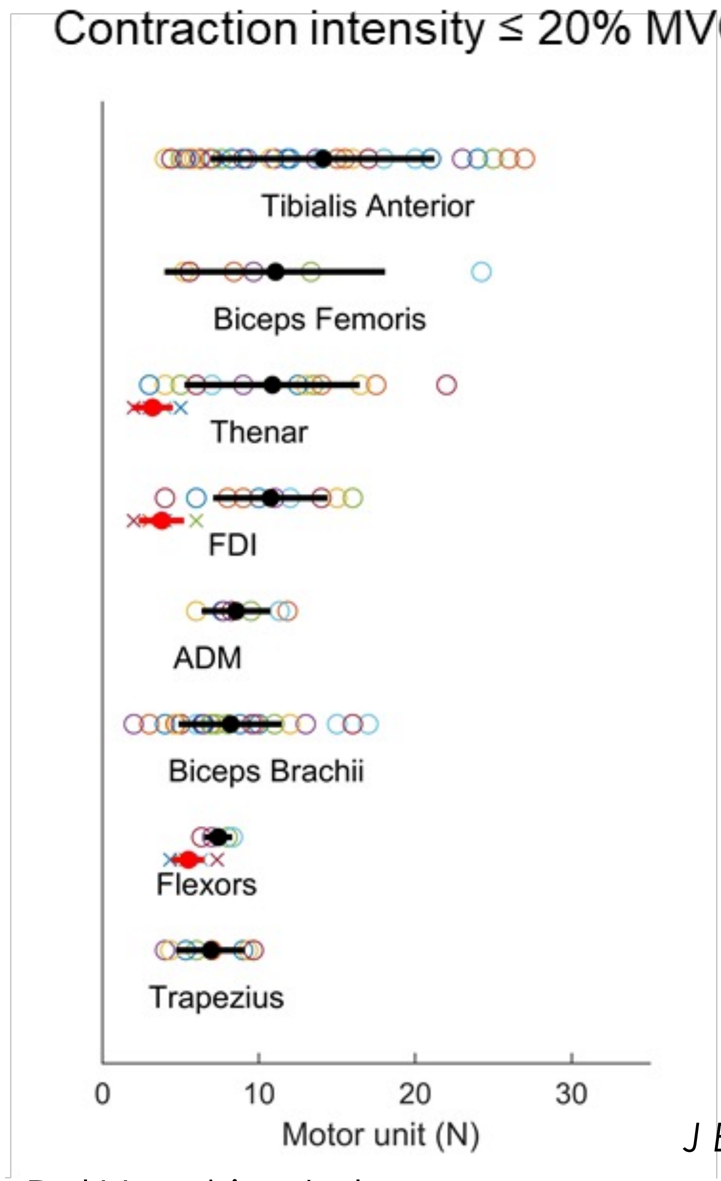




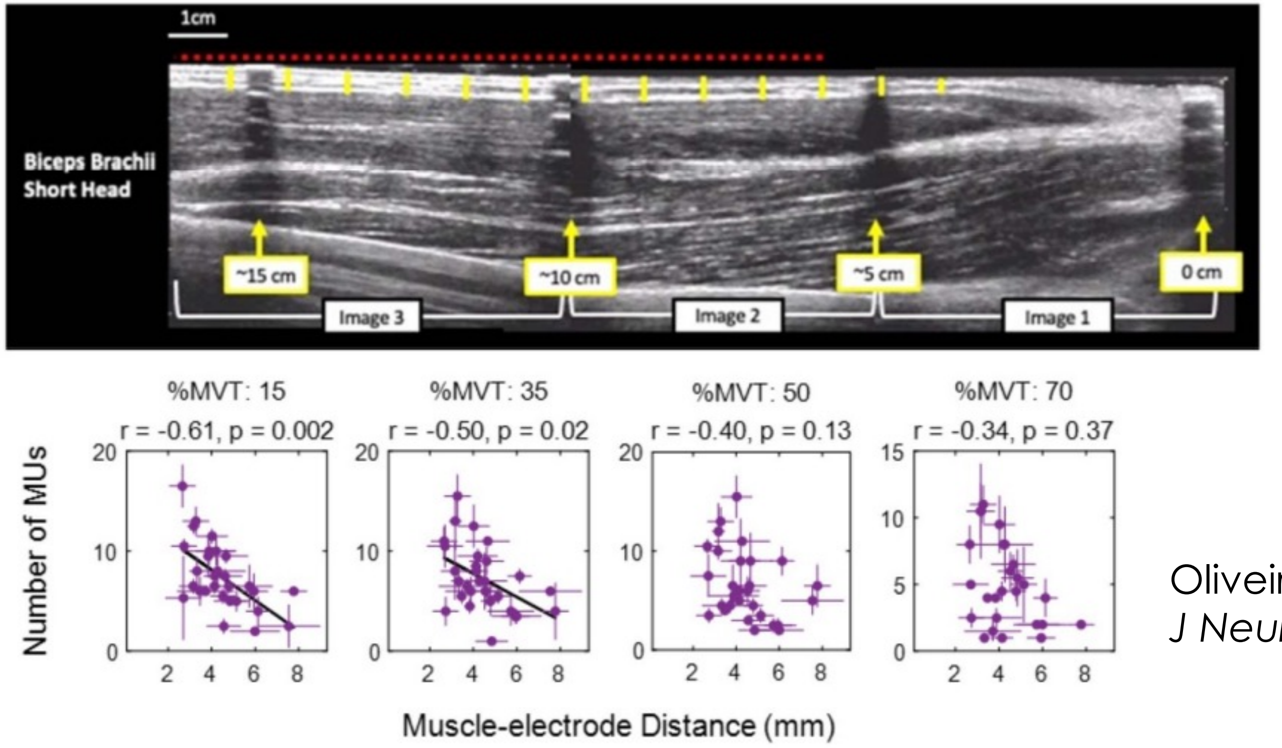


Aszmann et al. *The Lancet* 2015; Farina et al., *Nature Biomed Eng* 2017; Bergmeister et al. *Science Adv* 2018; Hahne et al. *Science Robotics* 2018; Salminger et al. *Science Robotics* 2019; Farina et al., *Nature Biomed Eng* 2021; Del Vecchio et al, *Science Advances*, 2021

Limitations of Surface EMG in MU Identification



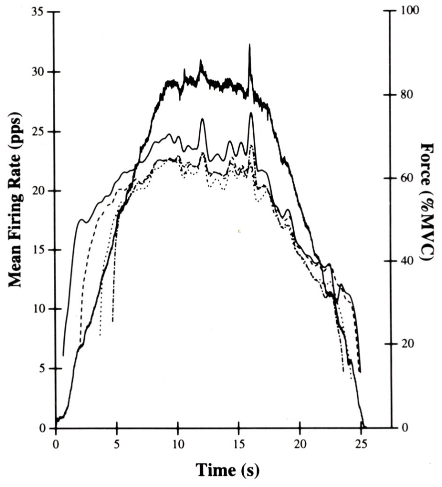
Del Vecchio et al
J Electromyogr & KInesiol, 2021

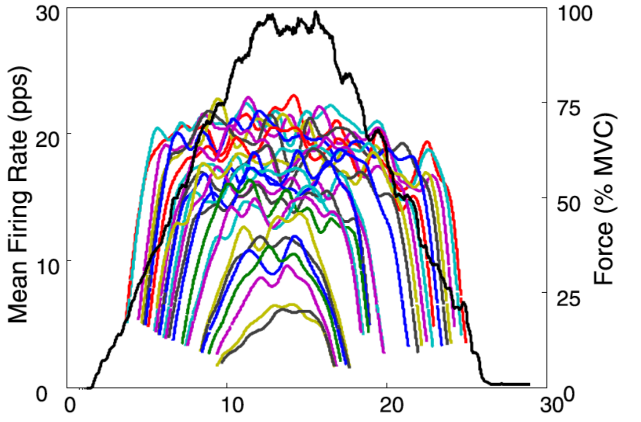


Oliveira et al
J Neural Eng 2022

Erim & De Luca *Muscle Nerve* 1996

Enoka
J Electromyogr Kinesiol 2019





De Luca & Contessa *J Neurophysiol* 2012

Main talk of today

Dr. Simon Avrillon