SSNR 2013

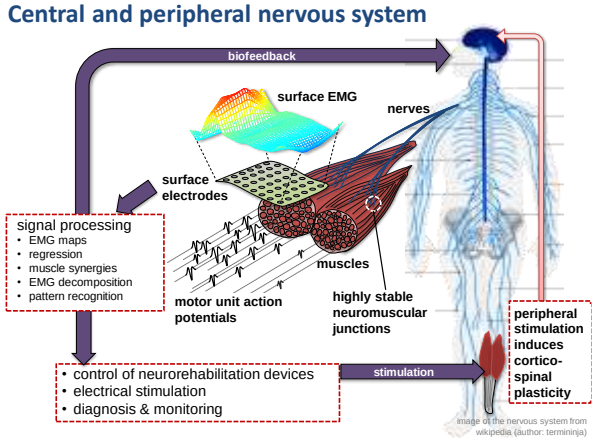
Understanding motor control of human movement by means of noninvasive motor unit identification

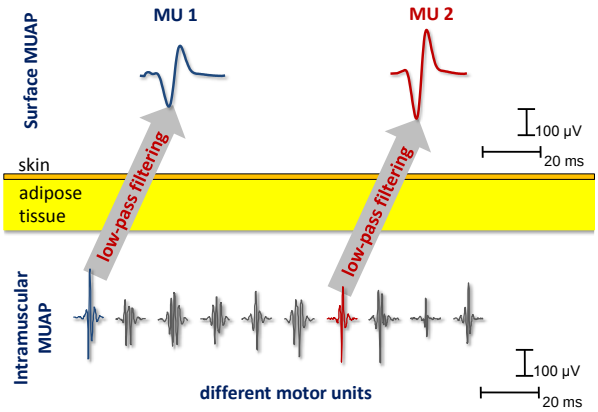
Aleš Holobar
[1] FEECS, UM, Slovenia

Outline

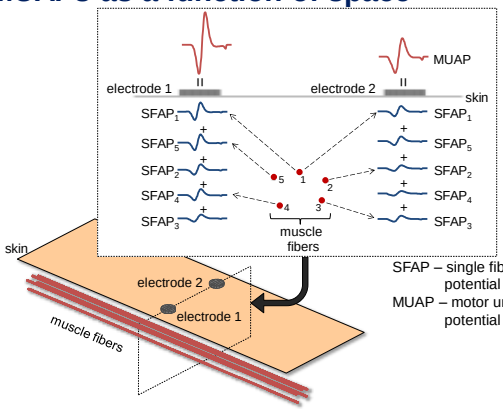
- EMG information revised
- Why to decompose EMG?
- Accuracy and representativenes
- Applications of decomposition
  - Pathological tremor
  - Stroke
  - CP
  - TMR

Central and peripheral nervous system



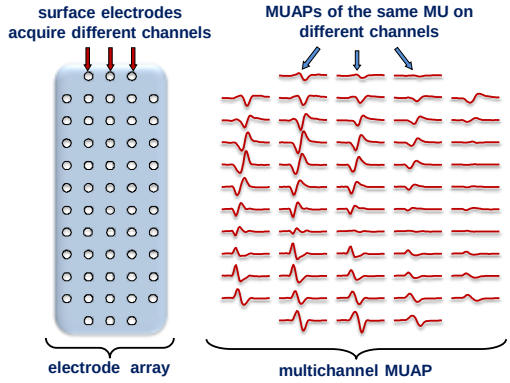


MUAPs as a function of space

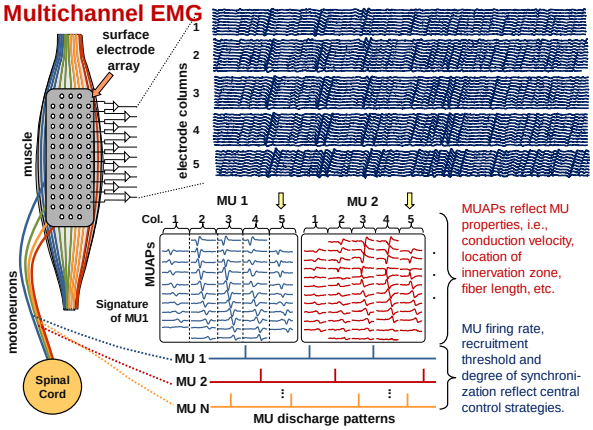


SFAP – single fiber action potential
MUAP – motor unit fiber potential

Arrays of surface electrodes & MUAPs



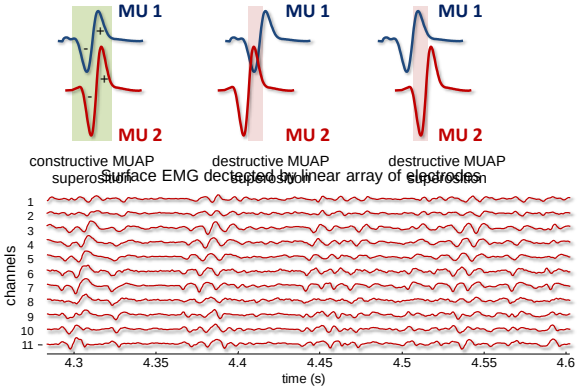
Multichannel EMG

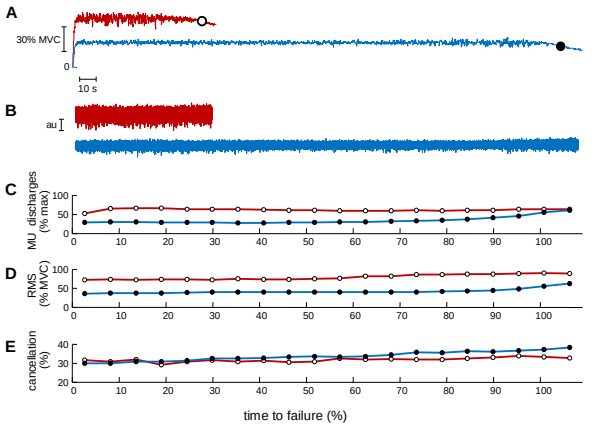


Why decomposition?

(global vs. local metrics)

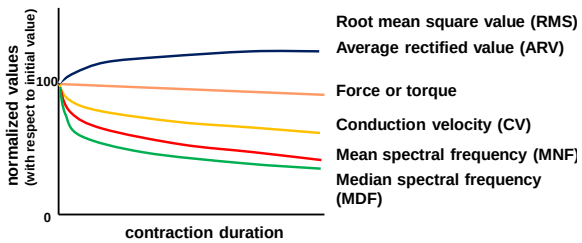
MUAP superposition & cancelation





Farina et al. Clinical Neurophysiology 2009

The Fatigue Plot

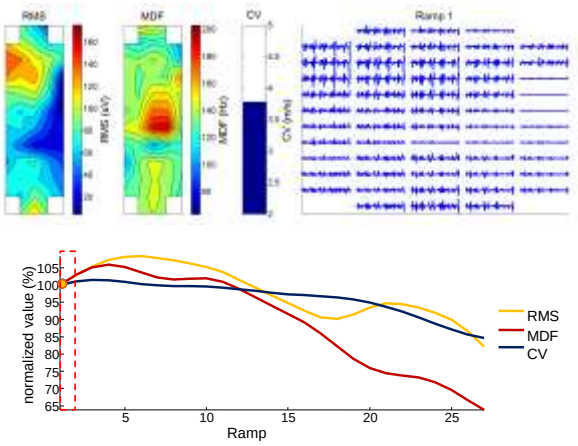


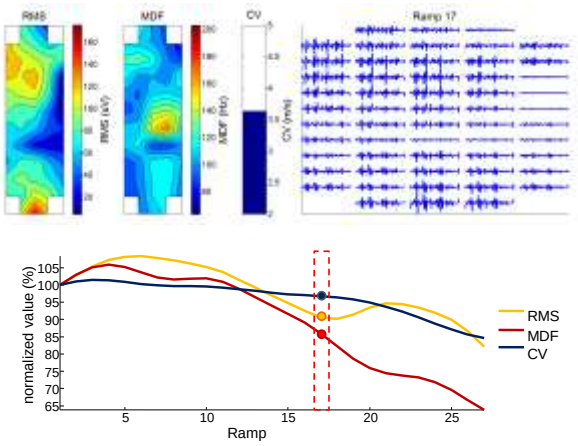
Global metrics (RMS, ARV, MNF, MDF) are easy to calculate but tricky to interpret. Their values depend on many internal factors.

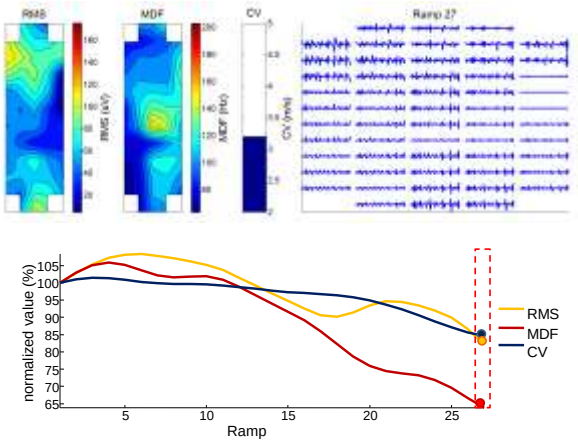
Experiment: Abductor Pollicis Brevis

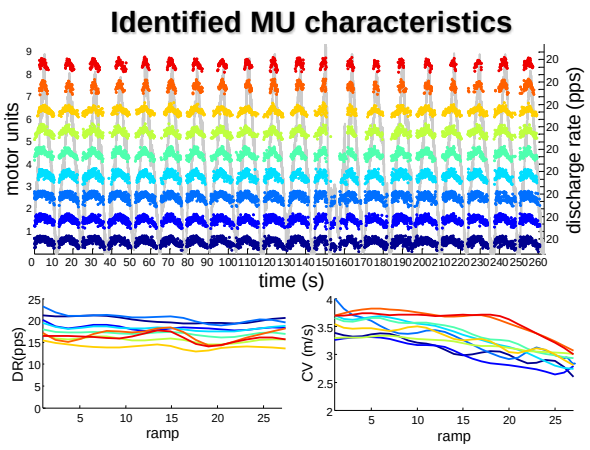
- ischemic condition
  (to accelerate fatigue and simulate higher contraction levels)
- isometric contractions
- force ramps:
  - from 0 % MVC to 10 % MVC and back to 0 % MVC in 12 seconds
  - normal & ischemic muscle condition
  - 27 ramp repetitions
  - 20 MUs identified,
  - in each force ramp, MUAPs were estimated by spike triggered averaging technique after decomposition.

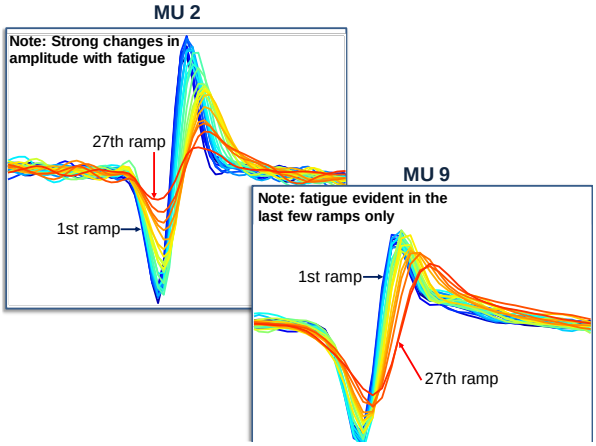
LISiN


RMS
MDF
CV
Ramp 1
normalized value (%)
Ramp
RMS
MDF
CV


RMS
MDF
CV
Ramp 17
normalized value (%)
Ramp
RMS
MDF
CV


RMS
MDF
CV
Ramp 27
normalized value (%)
Ramp
RMS
MDF
CV


Identified MU characteristics
motor units
discharge rate (pps)
time (s)
DR(pps)
ramp
CV (m/s)
ramp



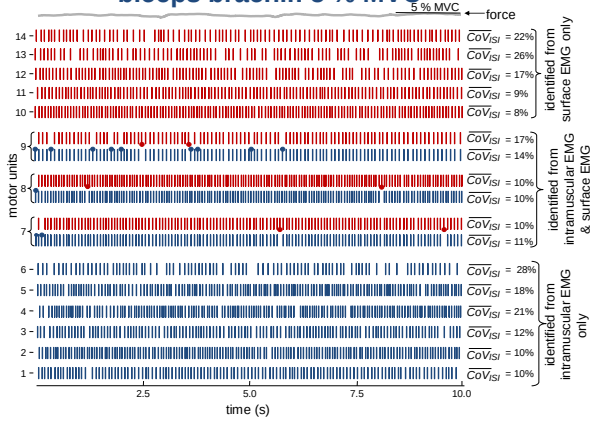
Can we trust the results?

(Accuracy)

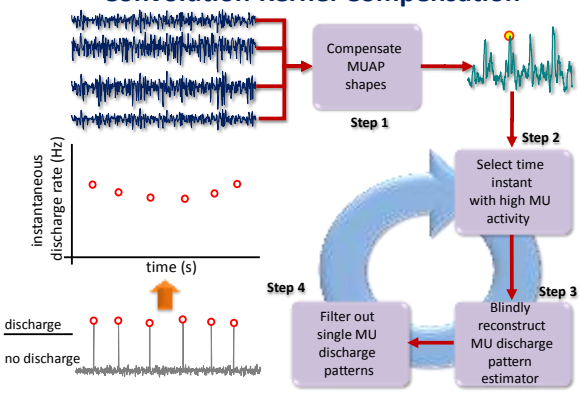
experiment: tibialis anterior & biceps brachii

- sEMG acquisition:
  - grid of 12 × 5 electrodes
  - IED: 3.5 mm
- iEMG acquisition:
  - a pair of wire electrodes made of Teflon coated steel
  - inserted with a 25 G needle proximal to the surface grid
- isometric contraction:
  - 5 %, 10 %, 15 %, 20 % MVC for 20 seconds
- EMG decomposition:
  - sEMG: CKC (Holobar et al.)
  - iEMG: EMGlab (McGill et al.)

biceps brachii: 5 % MVC

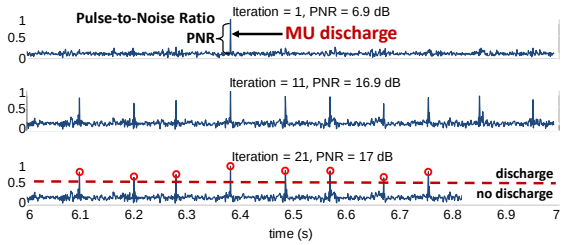


Convolution Kernel Compensation



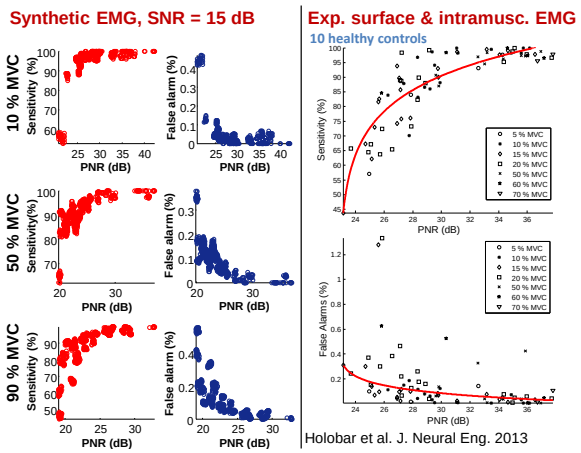
A. Holobar, D. Zazula: *IEEE Trans. on Signal Processing,* 2007, vol. 55, pp. 4487-4496.

Iterative identification of MU discharges



Pulse-to-Noise Ratio (PNR):
- applied to EVERY identified motor unit
- computationally efficient
- no additional experimental costs
- reliable indicator of accuracy of motor unit identification

A. Holobar et al. *Journal of Neural Engineering*, 2013.

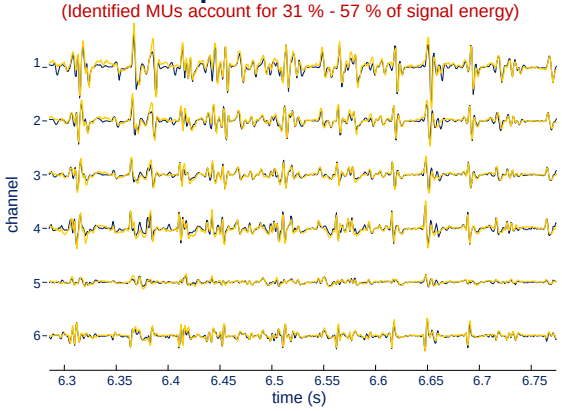


Holobar et al. J. Neural Eng. 2013

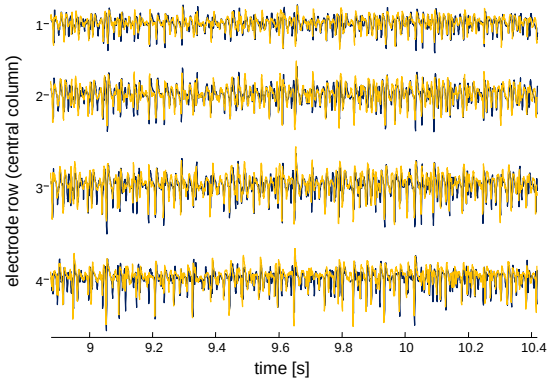
What do we actually see?

(Representativeness)

Abductor pollicis brevis: 10 % MVC
(Identified MUs account for 31 % - 57 % of signal energy)



Biceps brachii: 75 % MVC, central column
(Identified MUs account for 14 - 49 % of signal energy)



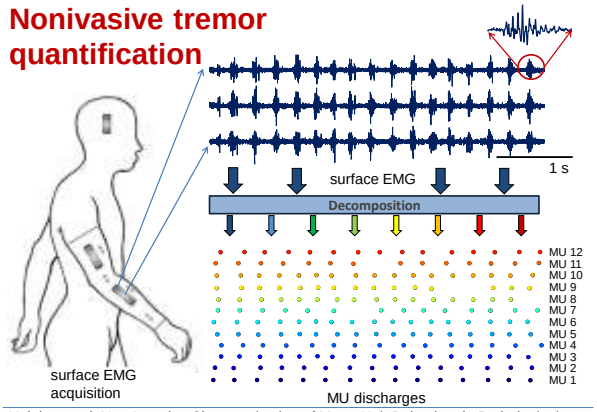
Applications of surface EMG Decomposition

Non-invasive tremor quantification

- **Tremor** is the most common movement disorder and it is strongly increasing in incidence and prevalence with ageing.
  - **Essential tremor**: ~ 4% of the population above 65 years of age
  - **Parkinsonian tremor**: ~1% of the population over the age of 50
  - **Cerebellar tremor**: ~ 0.1% of the global population
- **Tremor diagnosis:** 30% to 50% of patients diagnosed with essential tremor (ET) do not have ET

  J. Benito-León, E.D.Louis: Nat Clin Pract Neurol 2006
- **No tool for noninvasive studies of tremor** on the level of individual motor units:
  - **preprocessing of surface EMG** in order to increase the information on neural drive – **contradictory results**
  - MU studies limited to **invasive needle investigations** & **controlled clinical environment**

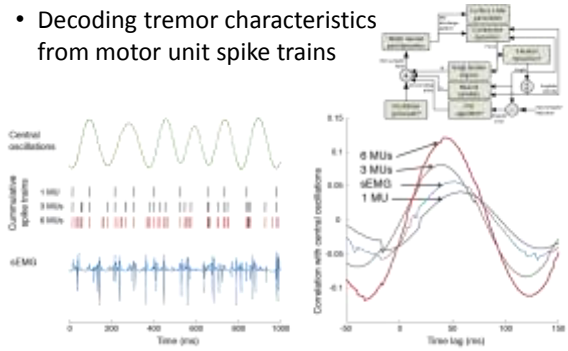
Nonivasive tremor quantification



Holobar et al. Non-Invasive Characterization of Motor Unit Behaviour in Pathological Tremor, J. of Neural Engineering 2012.

Decomposed vs. raw surface EMG

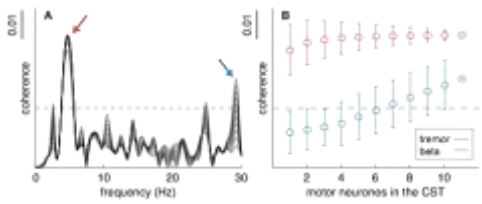
- Decoding tremor characteristics from motor unit spike trains



1. Dideriksen JL, Gallego JA, Farina D. *Proc MBEC Nordic Baltic Conf* 2011
2. Farina D, Negro F, Jiang N. *J Physiol* 2012

Corticospinal coherence

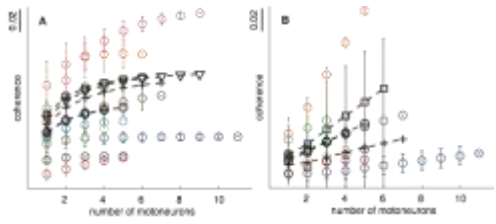
- Significant at the tremor frequency (9/9 pat) and the beta band (8/9 pat)
- At the tremor frequency, it saturates with the number of motor neurons => there is a common tremor-related cortical input[1] (linearity)



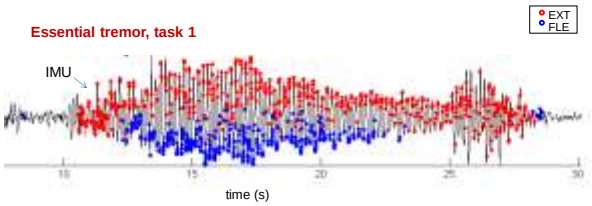
1. Negro F, Farina D. *J Physiol* 2011

Corticospinal coherence

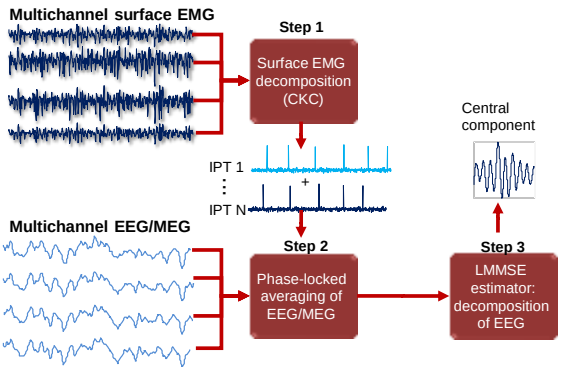
- Coherence at the tremor frequency "saturates" with ~5 motor neurons, and is significant when 1-2 are sampled.



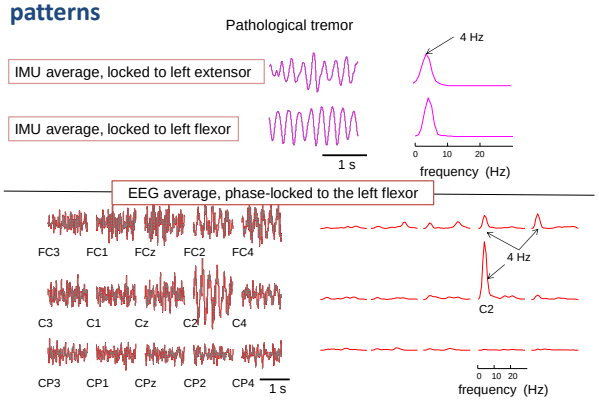
Motor units & IMUs



EMG-driven EEG decomposition

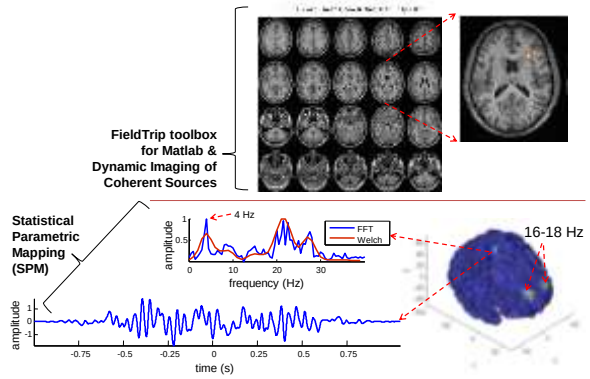


IMU/EEG averaging, phase-locked to MU discharge patterns



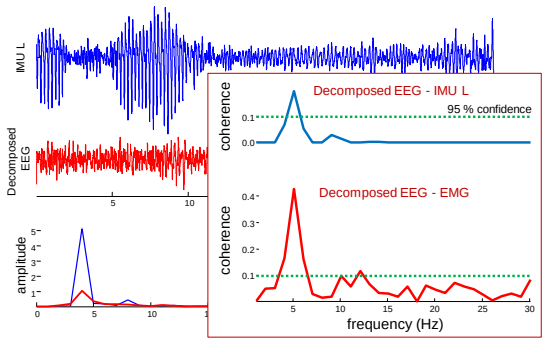
Inverse problem of EEG/MEG: Cortical activity

EEG averaging phase locked to **left flexor**



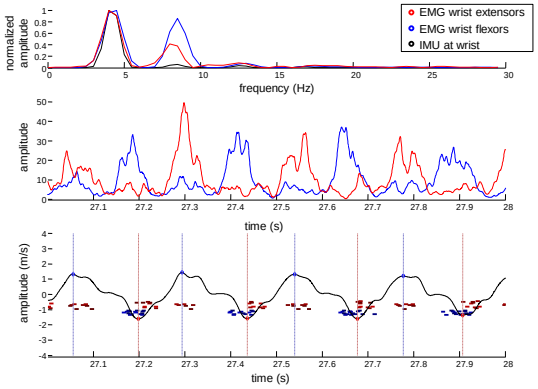
Step 3: Extracted tremor components

PD patient, EEG decomposition locked to MUs of left wrist flexors



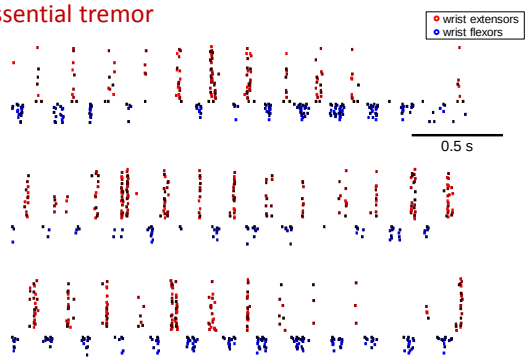
Tremor higher harmonics & MU discharges

Parkinsonian tremor

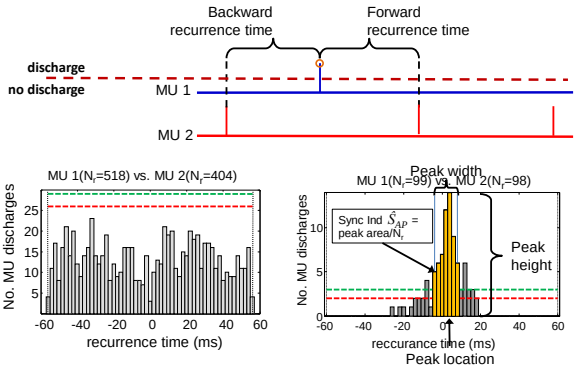


Motor unit discharge pattern

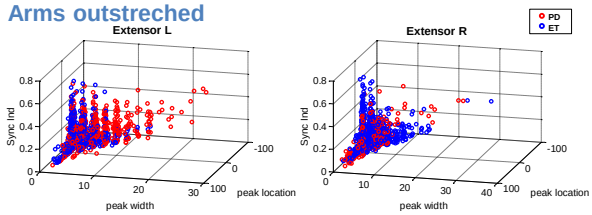
essential tremor



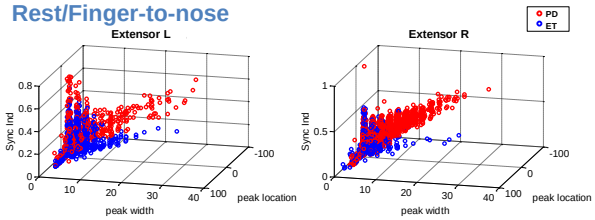
Motor unit synchronization



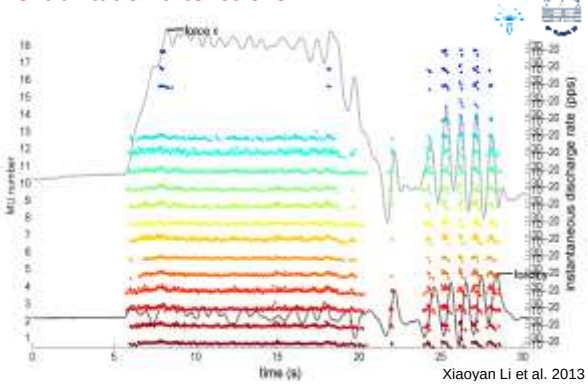
Arms outstreched



Rest/Finger-to-nose

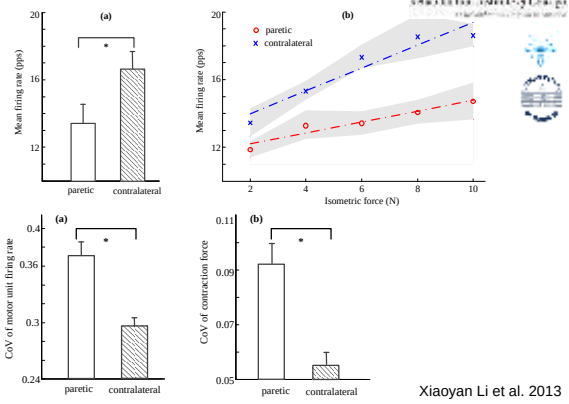


Motor unit discharge patterns:
Rehabilitation after stroke



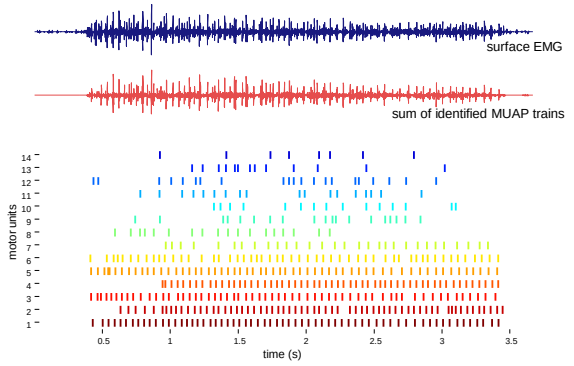
Xiaoyan Li et al. 2013

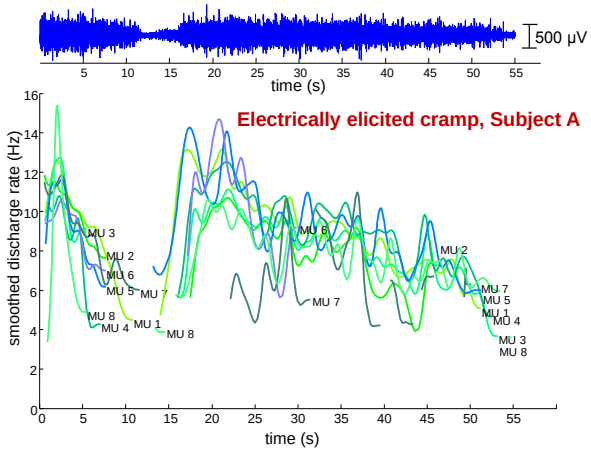
Rehabilitation after stroke (N=9)



Xiaoyan Li et al. 2013

Motor unit discharge patterns:
Cerebral palsy

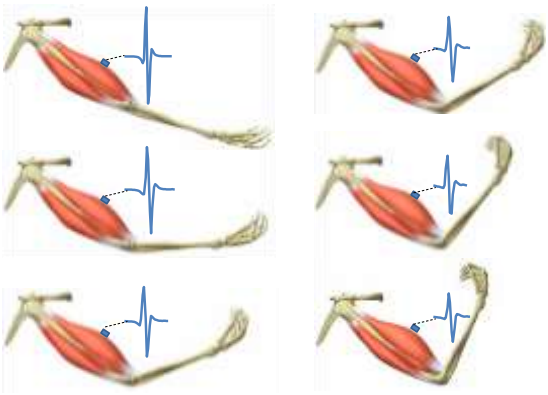




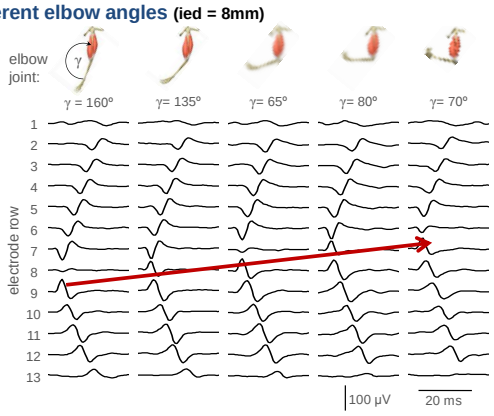
Isometric means no movement…

(dynamic surface EMG)

MUAP shape when muscle shortens

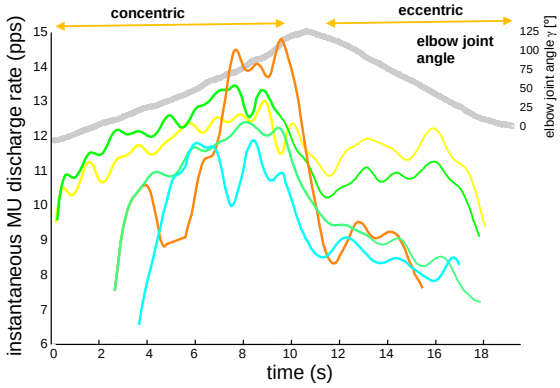


MUAPs as detected by the central electrode column at different elbow angles (ied = 8mm)



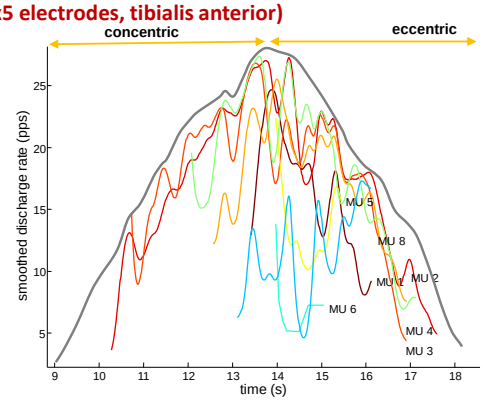
Experimental dynamic surface EMG

(13x5 electrodes, biceps brachii)



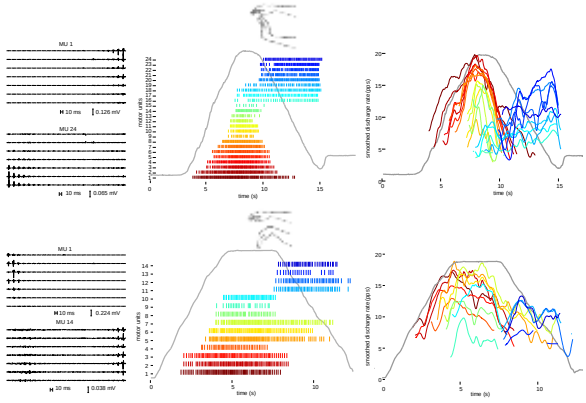
Experimental dynamic surface EMG

(13x5 electrodes, tibialis anterior)



Wrist flexion & extension

Farina et al. IEEE TNRSE 2013



Targeted muscle reinnervation

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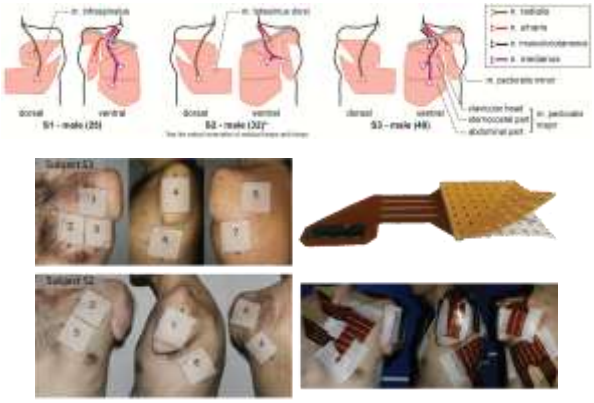
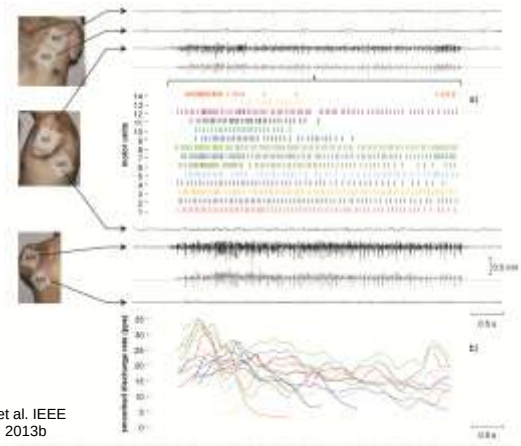


Targeted muscle reinnervation
Elbow flexion



Farina et al. IEEE TNRSE 2013b

Conclusions

- Insight into central control strategies:
  - a high safety margin at the nerve-muscle synapse
  - nonlinear vs. linear projections of neural codes: **EMG vs. decomposition**
  - new unobtrusive arrays of surface electrodes: smart garments, epidermal electronic systems - "tattoos" (Kim et al. Science, 2011)
- Novel decomposition algorithms:
  - robust to high **MU synchronization**
  - robust to high **MU inter-discharge interval variability**
  - applicable to **high muscle contractions** / large number of active MUs
  - applicable to **dynamic EMG signals**
- **Applications** (our group + partners):
  - quantification of Parkinsonian and essential tremor
  - rehabilitation after stroke,
  - CP
  - type 2 diabetes,
  - muscle cramps,
  - healthy and cleft lips,
  - TMR…

What is your application?