SNNR2013 Workshop: Multichannel surface EMG

DECOMPOSITION OF SURFACE EMG

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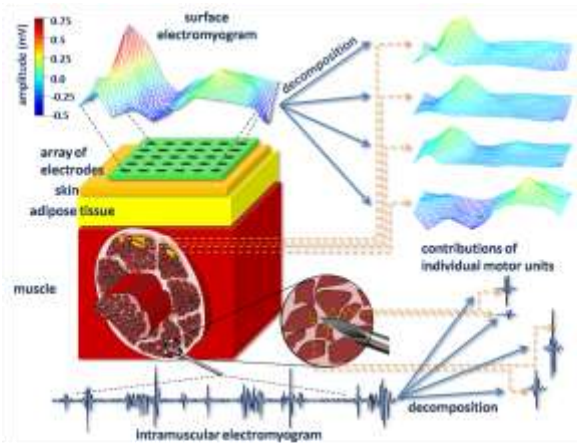
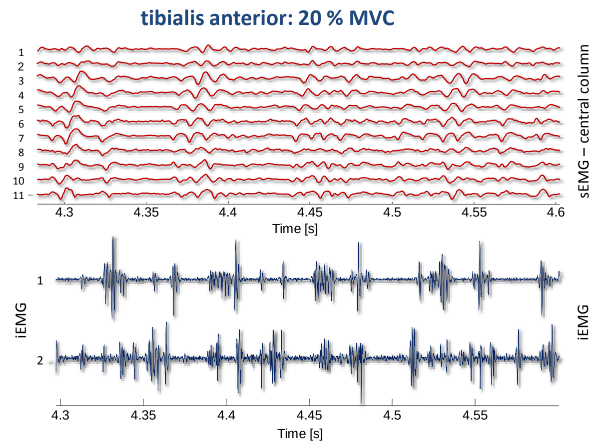
Lecture outline

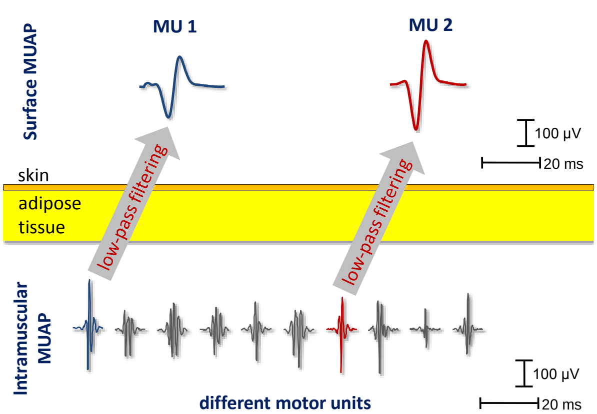
- EMG: surface vs. intramuscular
- Decomposition of surface EMG:
  - template matching
  - blind source separation
- Verification of decomposition
- Demonstration of decomposition
  - DEMUSE tool

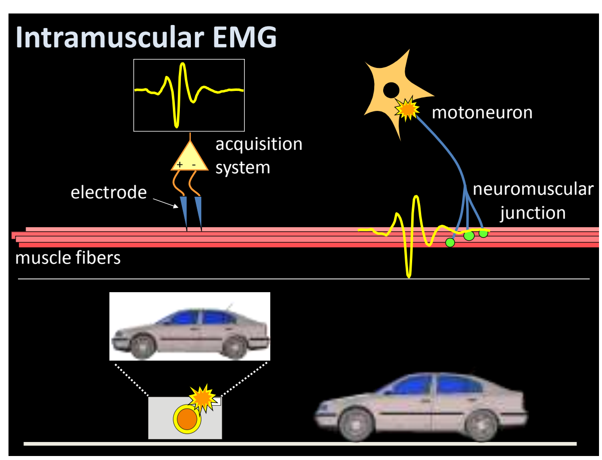
Part 1

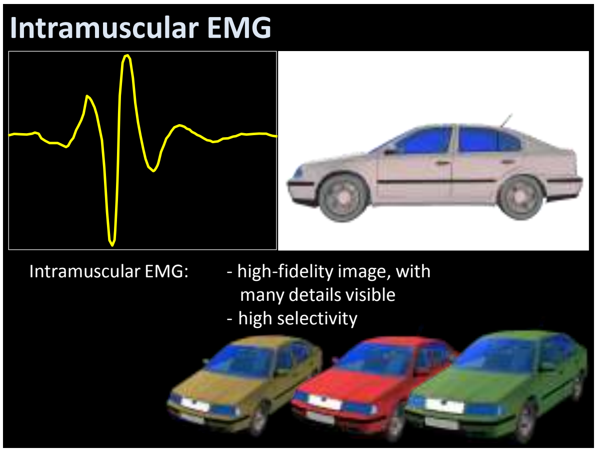
Intramuscular vs. surface EMG

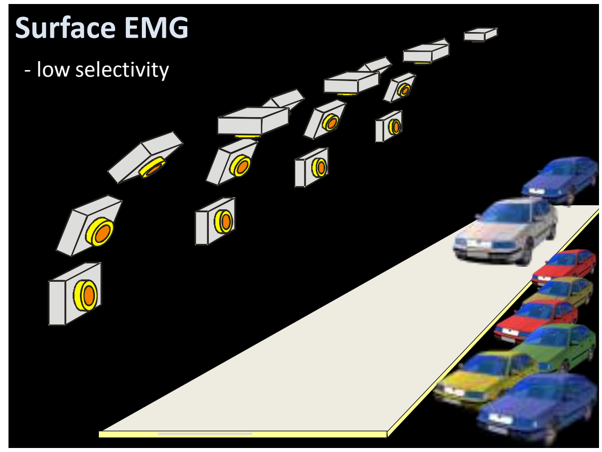

surface electromyogram
amplitude [mV]
decomposition
array of electrodes
skin
adipose tissue
muscle
contributions of individual motor units
decomposition
intramuscular electromyogram

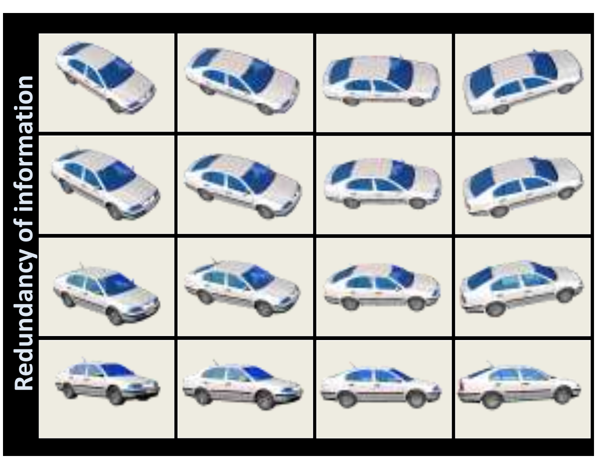

tibialis anterior: 20 % MVC
sEMG – central column
Time [s]
iEMG
iEMG
Time [s]

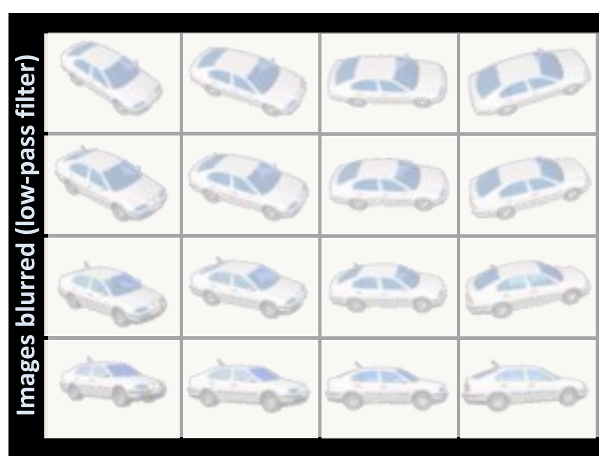

Surface MUAP
MU 1
MU 2
100 µV
20 ms
skin
adipose tissue
low-pass filtering
low-pass filtering
Intramuscular MUAP
different motor units
100 µV
20 ms


Intramuscular EMG
acquisition system
motoneuron
electrode
neuromuscular junction
muscle fibers

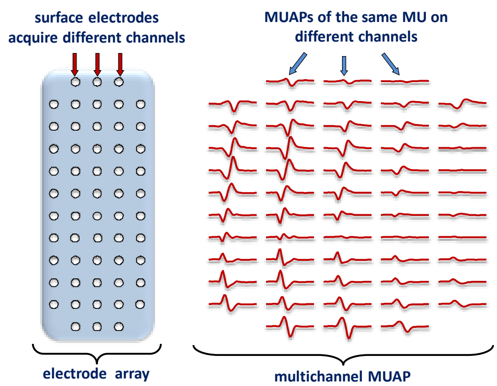

Intramuscular EMG
Intramuscular EMG:
- high-fidelity image, with many details visible
- high selectivity


Surface EMG
- low selectivity

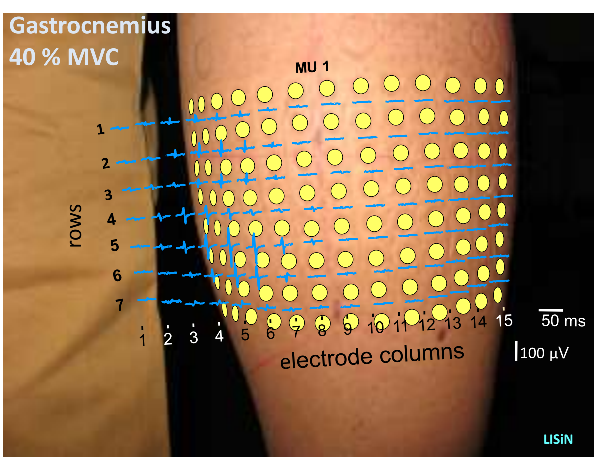

Redundancy of information


Images blurred (low-pass filter)

Arrays of surface electrodes & MUAPs

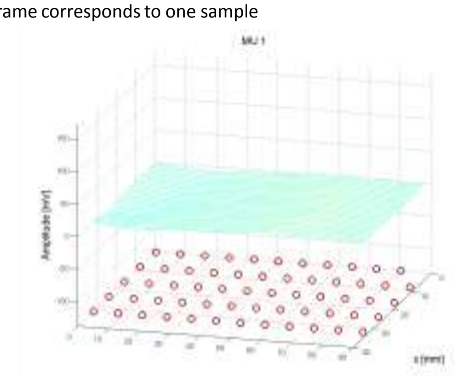


Arrays of surface electrodes: high-density EMG

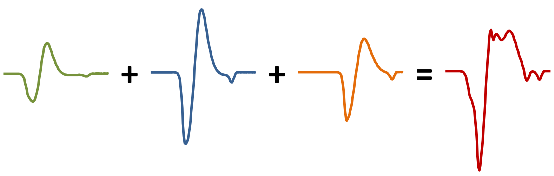


3D MUAP maps in time

- each frame corresponds to one sample



Problem of superimpositions



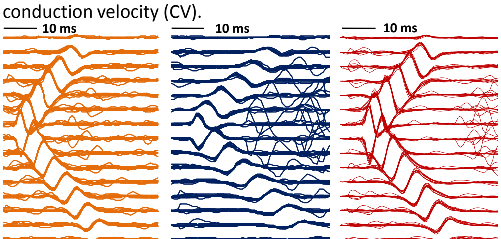
Action potentials of different MUs algebraically sum up and form complex interference pattern. The summation can be destructive (due to polyphasic shape of MUAPs): the negative phase of one MUAP can cancel out the positive phase of another MUAP.

Part 2

Decomposition

Manual identification and classification of action potentials

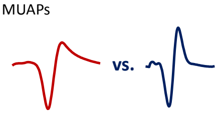
Templates of three MUs identified in the surface EMG signal recorded during a low level contraction (biceps brachii). The identified action potentials of the same MU are shown superimposed. It is possible to identify the position of innervation zone (IZ) and the tendons and to estimate the conduction velocity (CV).



Automatic decomposition: possible approaches

Space of MUAPs / MUAP trains
Template matching

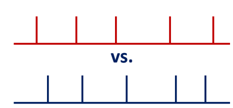
morphological differences of MUAPs



- \+ **single or multichannel EMG**
- \- **sensitive to MUAP superimpositions**

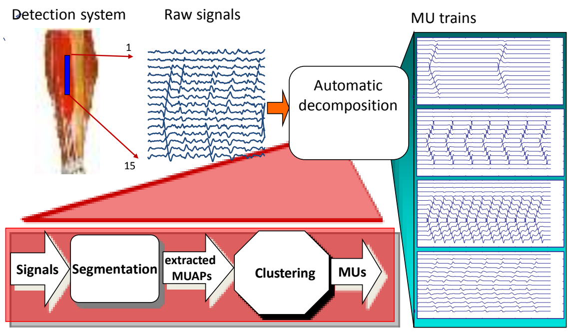
Space of MU discharge patterns / innervation pulse trains
Source separation

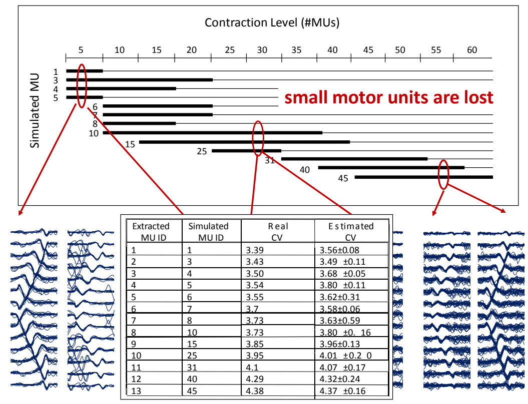
statistical properties of MU discharge patterns



- \+ **not sensitive to MUAP superimpositions**
- \- **multichannel EMG (large arrays of electrodes)**

Template matching for automatic SEMG decomposition

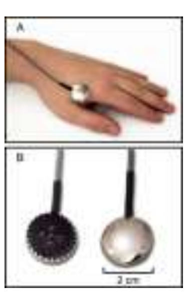


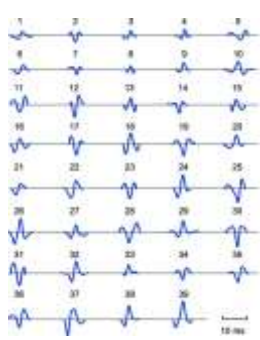


Extracted MU ID	Simulated MU ID	Real CV	Estimated CV
1	1	3.39	3.56±0.08
2	3	3.43	3.49 ±0.11
3	4	3.50	3.68 ±0.05
4	5	3.54	3.80 ±0.11
5	6	3.55	3.62±0.31
6	7	3.7	3.58±0.06
7	8	3.73	3.63±0.59
8	10	3.73	3.80 ±0. 16
9	15	3.85	3.96±0.13
10	25	3.95	4.01 ±0.2 0
11	31	4.1	4.07 ±0.17
12	40	4.29	4.32±0.24
13	45	4.38	4.37 ±0.16

Da Gazzoni M, Farina D, Merletti R. A new method for the extraction and classification of single motor unit action potentials from surface EMG signals. J Neurosci Methods. 2004 Jul 30;136(2):165-77.

Advanced Template matching tecniques

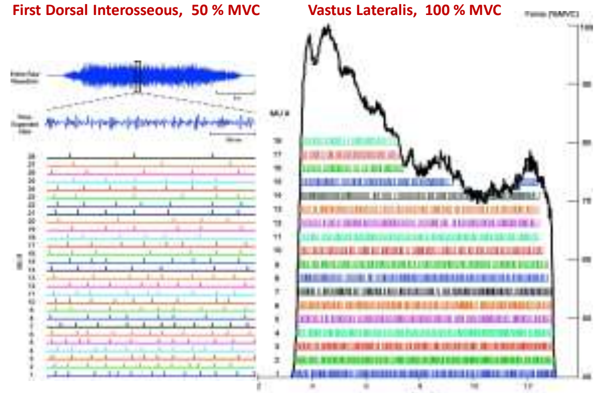




S. H. Nawab, S. S. Chang, C. J. De Luca: High-yield decomposition of surface EMG signals Clin. Neurophysiol (2010), doi:10.1016/j.clinph.2009.11.092

First Dorsal Interosseous, 50 % MVC

Vastus Lateralis, 100 % MVC



S. H. Nawab, S. S. Chang, C. J. De Luca: High-yield decomposition of surface EMG signals Clin. Neurophysiol (2010), doi:10.1016/j.clinph.2009.11.092

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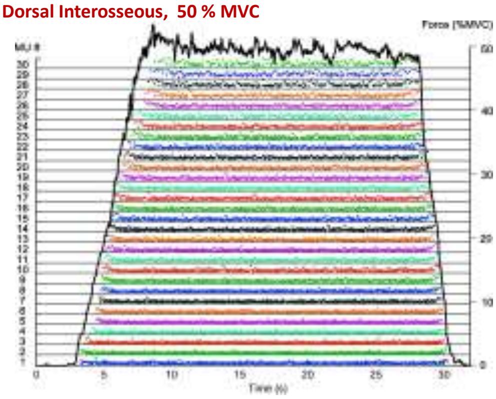
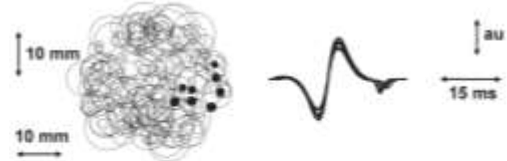


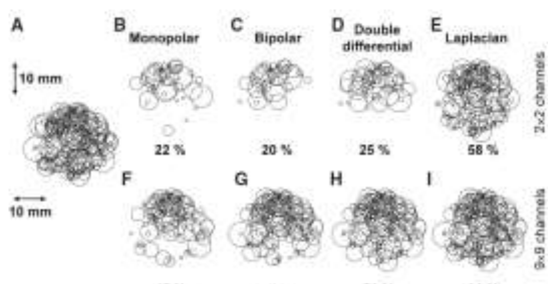
S. H. Nawab, S. S. Chang, C. J. De Luca: High-yield decomposition of surface EMG signals Clin. Neurophysiol (2010), doi:10.1016/j.clinph.2009.11.092

Motor unit identifiability: number of channels



Simulated bipolar recordings of motor-unit potentials in the long muscle (120-mm fiber length) from one location in the 11×11 electrode grid (central location). From the population of 200 motor units (circles in the left traces), a group of 8 (filled black circles in the left traces) was selected. These 8 motor units were located in different parts of the muscle and had slightly different sizes. A recording with one bipolar channel detected the potentials generated by the eight motor units, and these could not be distinguished from one another based on the criterion of 5% threshold in energy. In this simulation, the subcutaneous layer was 5 mm thick and the innervation zone was located at 20 mm in the longitudinal direction from the center of the long muscle. au: arbitrary units.

D. Farina, F. Negro, M. Gazzoni, R. M. Enoka: Detecting the Unique Representation of Motor-Unit Action Potentials in the Surface Electromyogram, *J Neurophysiol 100: 1223–1233, 2008.*



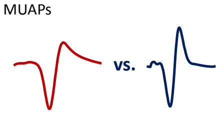
Representation of identifiable motor units in a simulated population for the long muscle (fiber length: 120 mm). *A: the territories* of all simulated motor units. From this population, the territories of motor units that were identifiable are shown for monopolar (*B, F), bipolar (C, G), double differential (D, H), and Laplacian (E, I) filtering in the case* of 4 (2×2) channels (*B, C, D, E) and 81* (9×9) channels (*F, G, H, I). The proportion* of identifiable motor units is also indicated as a percentage of the entire population.

D. Farina, F. Negro, M. Gazzoni, R. M. Enoka: Detecting the Unique Representation of Motor-Unit Action Potentials in the Surface Electromyogram, *J Neurophysiol 100: 1223–1233, 2008.*

Automatic decomposition: possible approaches

Space of MUAPs / MUAP trains
Template matching

morphological differences of MUAPs

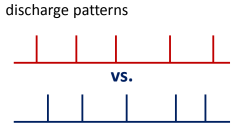


+ **single or multichannel EMG**

- **sensitive to MUAP superimpositions**

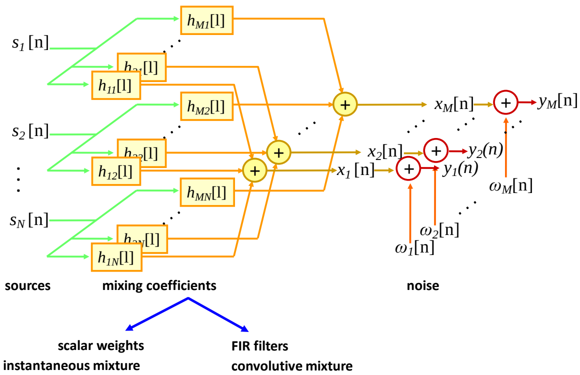
Space of MU discharge patterns / innervation pulse trains
Source separation

statistical properties of MU discharge patterns

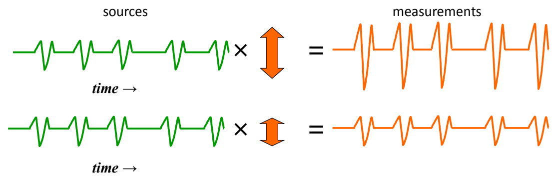


+ **not sensitive to MUAP superimpositions**
- **multichannel EMG (large arrays of electrodes)**

BSS - linear generative model



SEMG Modeling: instantaneous mixtures



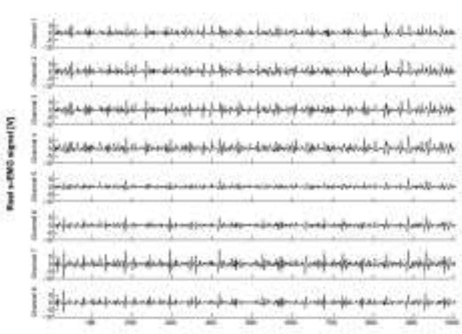
$$x_i[n] = \sum_j h_{ij} s_j[n]$$

+ Simple and well understood

- Cannot be used to model:

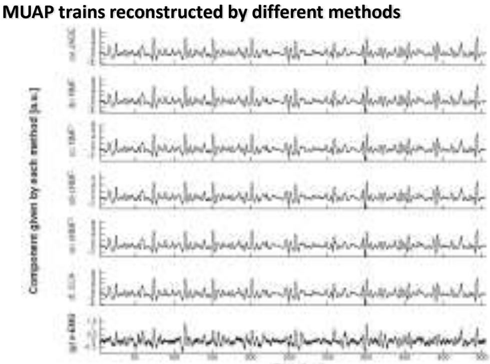
- delays due to propagation of MUAPs,
- differences in conduction velocities of MU muscle fiber,
- differences in orientation of MU muscle fibers,
- MUAP generation and extinction effect, etc.

BSS - instantaneous model: real SEMG signals (biceps brachii, isometric constant force contraction at 30 % MVC)



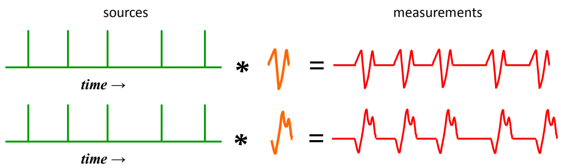
Theis, F.J., and García, G.A. (2006). On the use of sparse signal decomposition in the analysis of multi-channel surface electromyograms. Signal Processing 86, 603–623

BSS - instantaneous model: real SEMG signals MUAP trains reconstructed by different methods



Theis, F.J., and García, G.A. (2006). On the use of sparse signal decomposition in the analysis of multi-channel surface electromyograms. Signal Processing 86, 603–623

SEMG Modeling: convolutive mixture



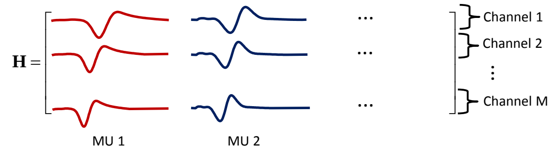
$$x_i[n] = \sum_j \sum_{l=0}^{L-1} h_{ij}[l]\, s_j[n-l]$$

+ can model arbitrary MUAP shapes
- complex, needs a large number of measurements

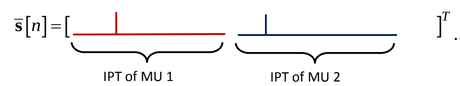
Surface EMG: Mixing process in a matrix form

$$\boxed{\mathbf{x}[n] = \mathbf{H}\bar{\mathbf{s}}[n] + \boldsymbol{\omega}[n]}$$

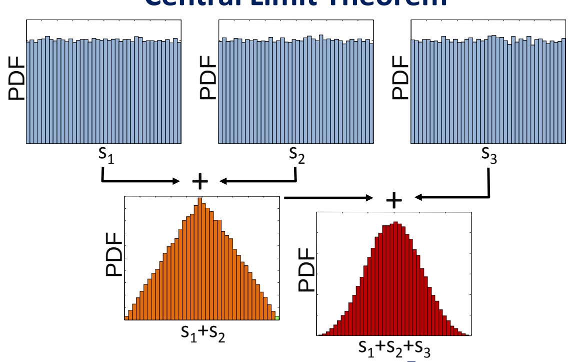
- **mixing matrix (MUAPs):**



- **extended vector of sources (innervation pulse trains):**



Central Limit Theorem



Idea: *maximize the nongaussianity* of $s_i=\mathbf{w}_i^T\mathbf{x}$ where $\mathbf{w}_i$ is a 'separating' vector to be determined.

Measures of nongaussianity:

Kurtosis or the fourth-order cumulant

$$kurt(s_i) = E\{s_i^4\} - 3\left(E\{s_i^2\}\right)^2$$

- kurtosis is zero for a Gaussian random variable
- it is positive for sparse signals
- If s is of unit variance ($E\{s^2\}=1$), then

$$kurt(s_i) = E\{s_i^4\} - 3$$

Gradient-based optimization algorithm:

1. Initialize separation vector: $\mathbf{w}_i = \mathbf{0}$

2. update separation vector: $\mathbf{w}_i = \mathbf{w}_i + \dfrac{\partial J(s_i)}{\partial \mathbf{w}_i}\mathbf{x}$

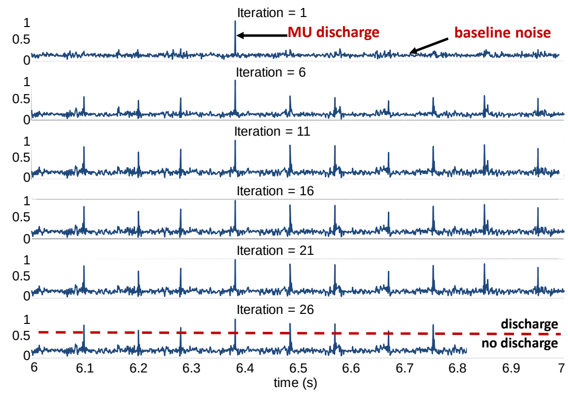
3. normalize of separation vector: $\mathbf{w}_i = \dfrac{\mathbf{w}_i}{\|\mathbf{w}_i\|}$
(to prevent trivial solution $\mathbf{w}_i=\mathbf{0}$)

4. reconstruct source s_i : $s_i = \mathbf{w}_i^T \mathbf{x}$

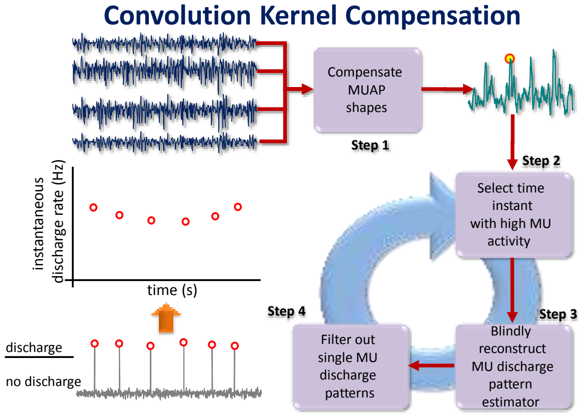
iterate optimization of separation vector

$J(s_i)$ - scalar cost function, such as kurtosis

Iterative MU identification



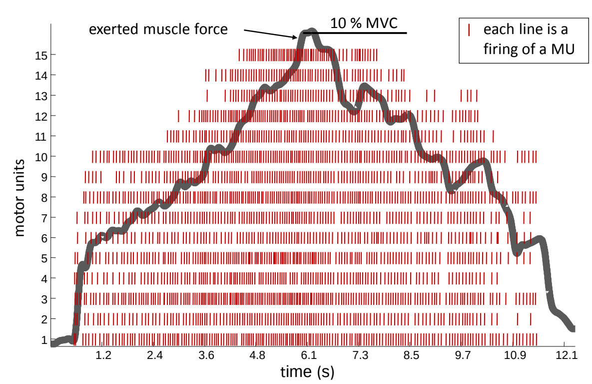
Convolution Kernel Compensation



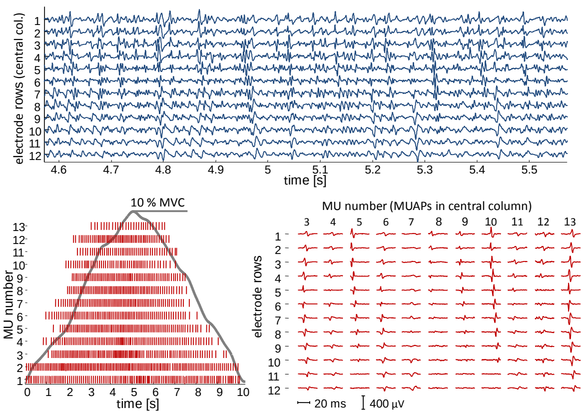
A. Holobar, D. Zazula: *IEEE Trans. on Signal Processing*, 2007, vol. 55, pp. 4487-4496.

Identified MU discharge patterns

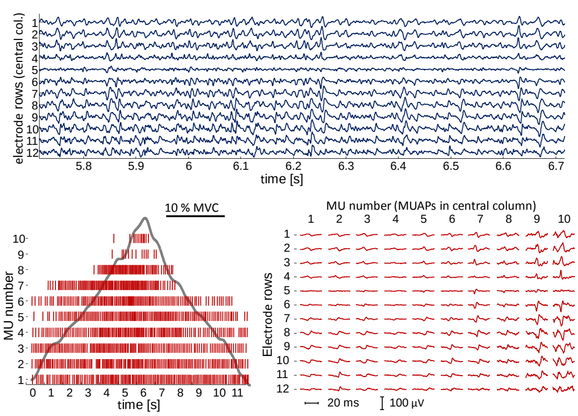
abductor pollicis brevis, isometric contraction at 10 % MVC



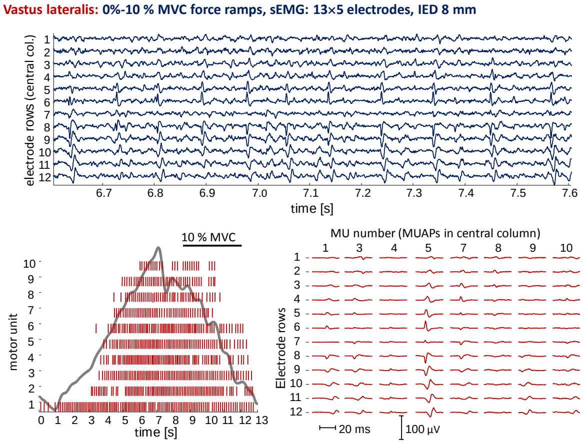
Biceps brachii: 0%-10% MVC force ramps, sEMG: 13×5 electrodes, IED 8 mm



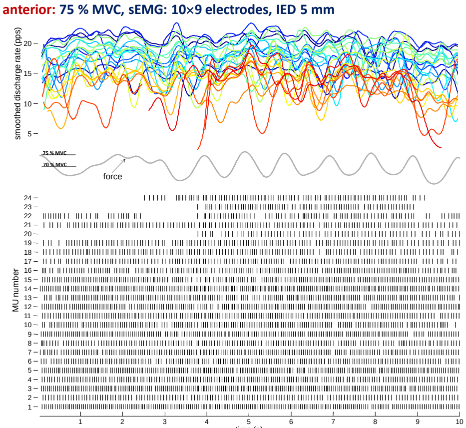
U. Trapezius: 0% - 10 % MVC force ramps, sEMG: 13×5 electrodes, IED 8 mm



Vastus lateralis: 0%-10 % MVC force ramps, sEMG: 13×5 electrodes, IED 8 mm



Tibialis anterior: 75 % MVC, sEMG: 10×9 electrodes, IED 5 mm

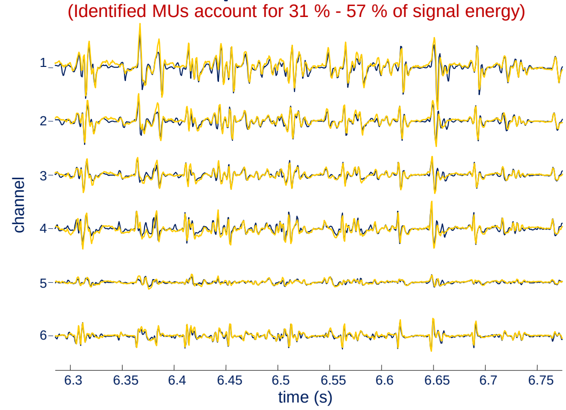


Part 3

Verification

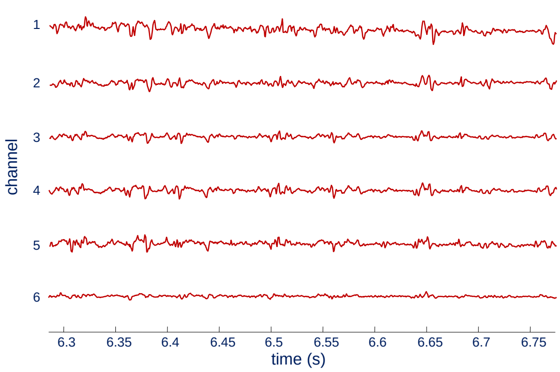
Abductor pollicis brevis: 10 % MVC

(Identified MUs account for 31 % - 57 % of signal energy)



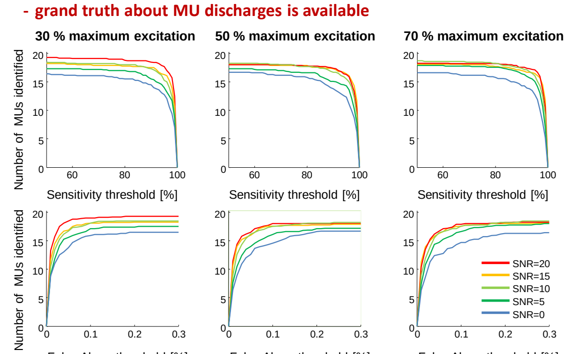
Residual after subtraction of MUAP trains

(Identified MUs account for 31 % - 57 % of signal energy)



Advanced surface EMG simulators:

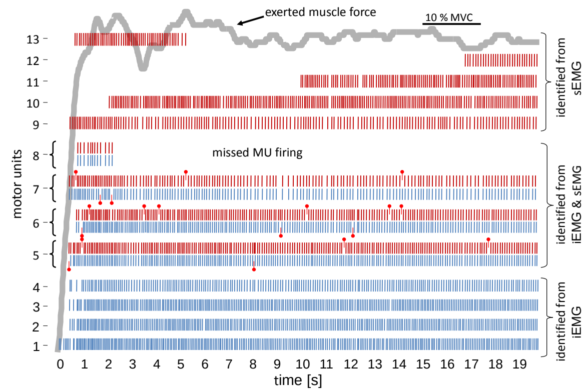
- **highly detailed testing of different factors that are hard to control in experiments (SNR, number of active MUs, muscle geometry…)**
- **grand truth about MU discharges is available**



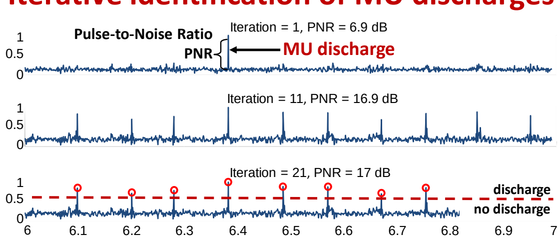
Concurrent acquisition of surface and intramuscular EMG:
abductor digiti minimi

- sEMG acquisition:
  - grid of 13 × 5 electrodes
  - IED: 3.5 mm
- iEMG acquisition:
  - a pair of wire electrodes made of Teflon coated stainless steel
  - inserted into the muscle with a 25 G needle proximal to the surface grid
- isometric contraction:
  - 10 % MVC for 20 seconds
- EMG decomposition:
  - sEMG: CKC (Holobar et al.)
  - iEMG: EMGlab (McGill et al.)

Abductor digiti minimi: 10 % MVC, constant isometric contraction
reconstructed MU discharge patterns



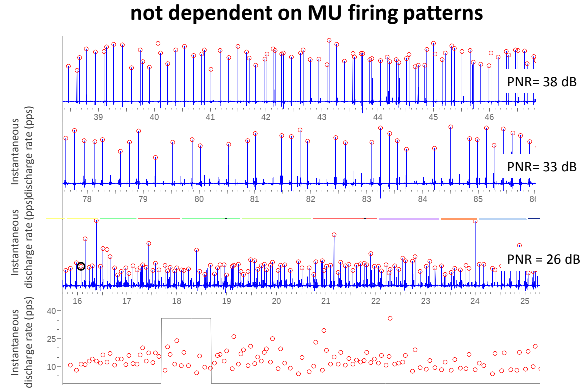
Iterative identification of MU discharges

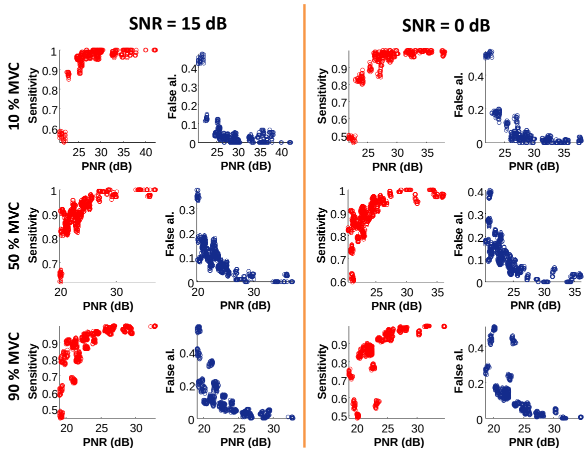


Pulse-to-Noise Ratio (PNR):
- applied to EVERY identified motor unit
- computationally efficient
- no additional experimental costs
- reliable indicator of accuracy of motor unit identification

A. Holobar et al. A signal-based approach for assessing the accuracy of high-density surface EMG decomposition, 6th International IEEE EMBS Conference on Neural Engineering, In press, 2013.

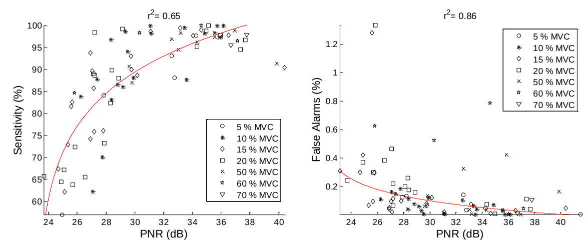
Pulse-to-Noise Ratio (PNR)
not dependent on MU firing patterns





PNR – validation with intramuscular EMG

10 healthy controls



Holobar et al. 2013

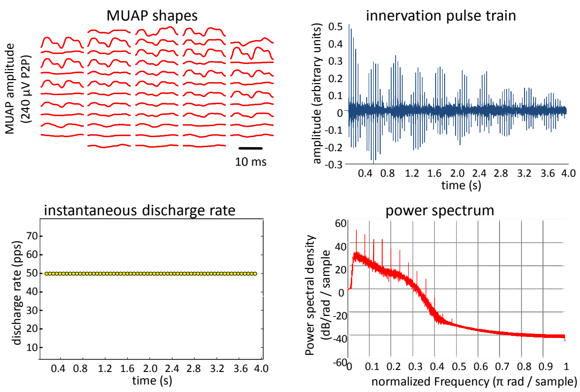
Part 4

Demonstration

DEMUSE

Decomposition of multichannel surface EMG

Name the intruder: line interference



Conclusions

- Surface EMG records the activity of several superficial MUs (problem of MUAP superimpositions)
- Computer-aided decomposition techniques help identify characteristics of individual MUs
  - MU conduction velocity
  - fiber length, position of innervation zone
  - MU recruitment/derecruitment
  - MU discharge patterns, instantaneous discharge rates (MU common drive, MU synchronization)
- Currently (a.d. 2013), non-invasive identification of up to 40 concurrently active MUs (in isometric condition) and up to 20 MUs (in dynamic condition) is possible
- Algorithms for decomposition are under intensive development.