MU filters and hdEMG processing pipelines

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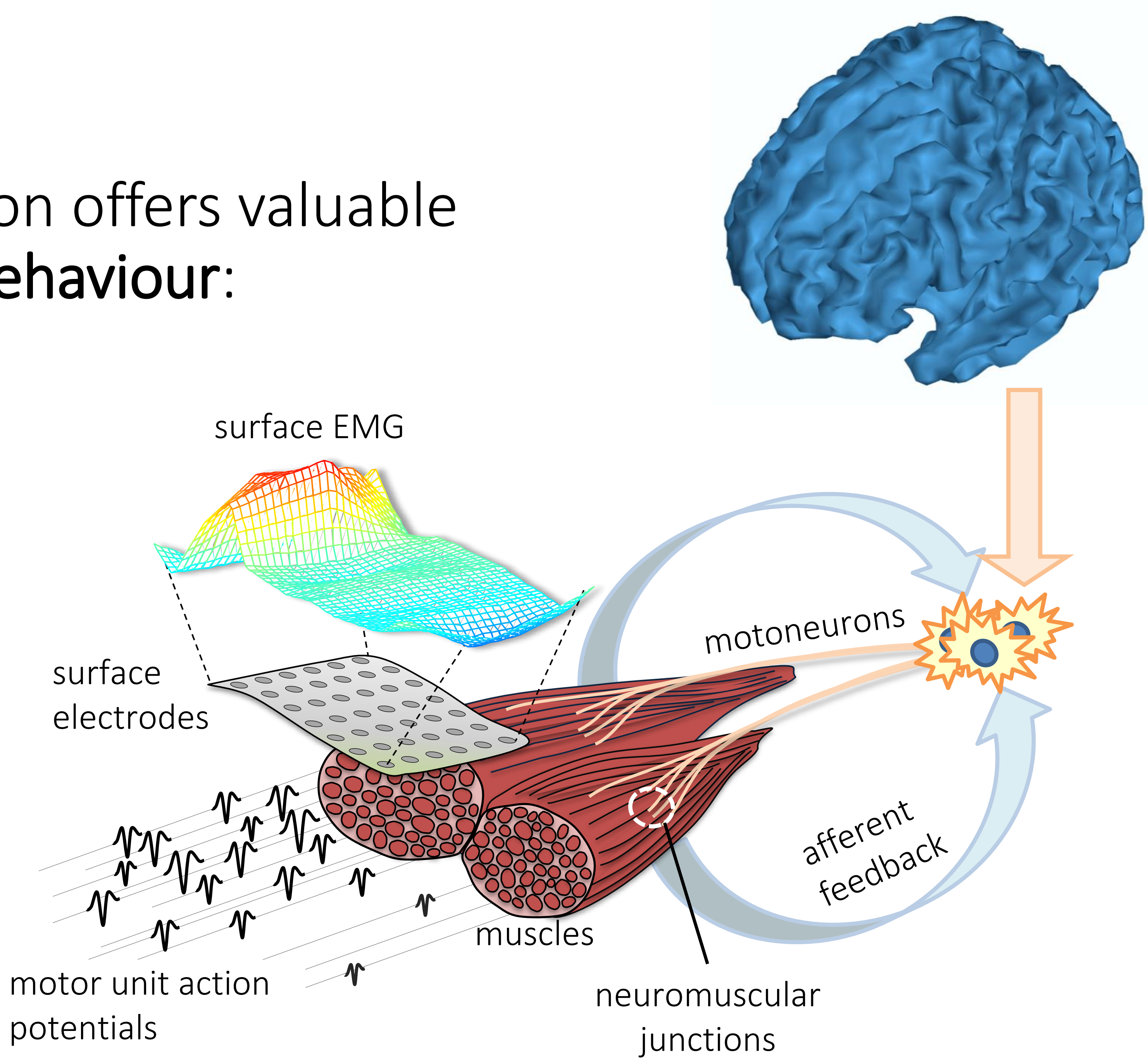
MOTIVATION

Motor Unit (MU) identification offers valuable insight into **neural codes & behaviour**:

- In non-fatiguing voluntary contractions MUs fire **asynchronously**
- Pathologies change the MU firing & synchronization patterns
- In elicited contractions, MU firings are highly (but not completely) **synchronised**
- **MU firing patter in always sparse.**



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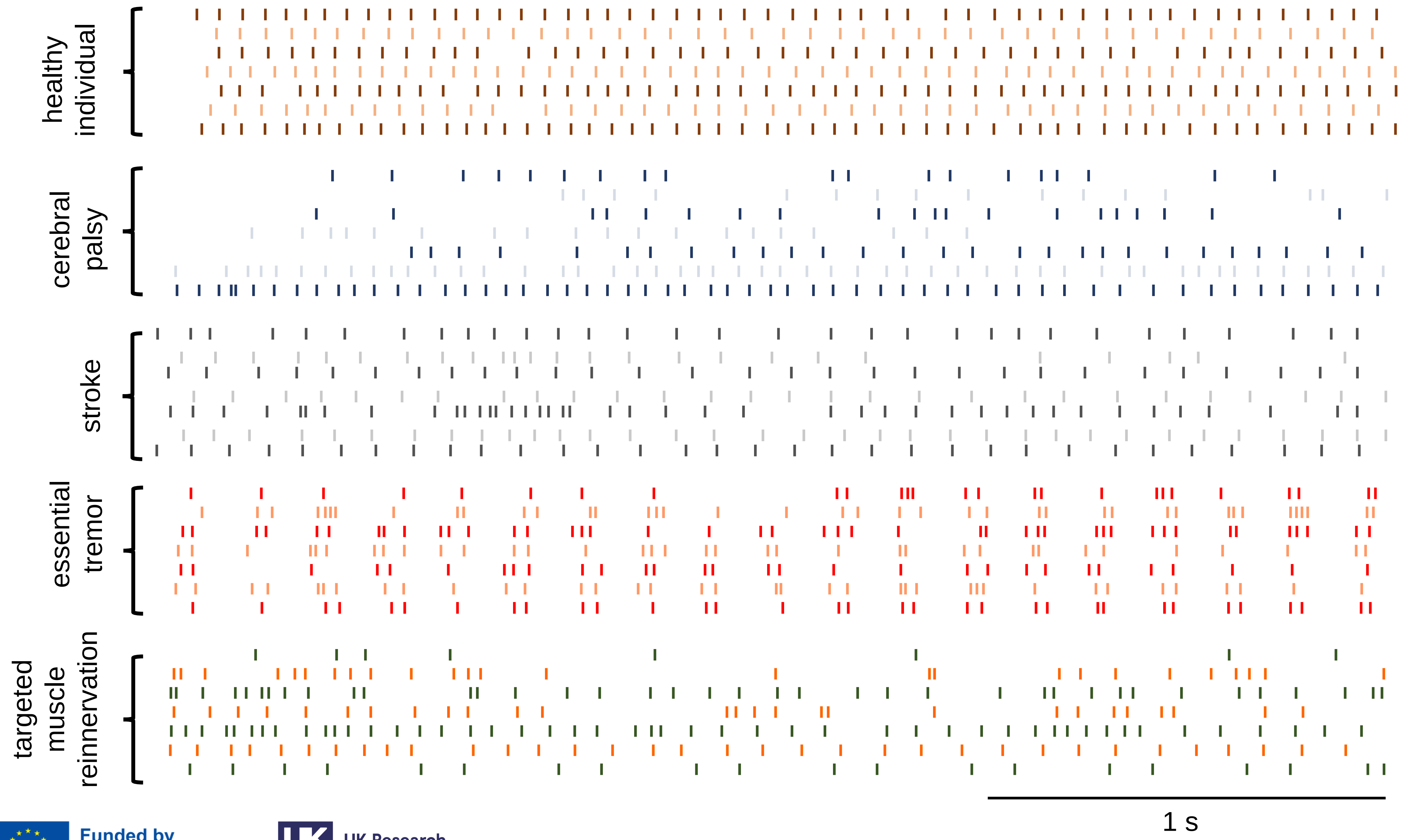

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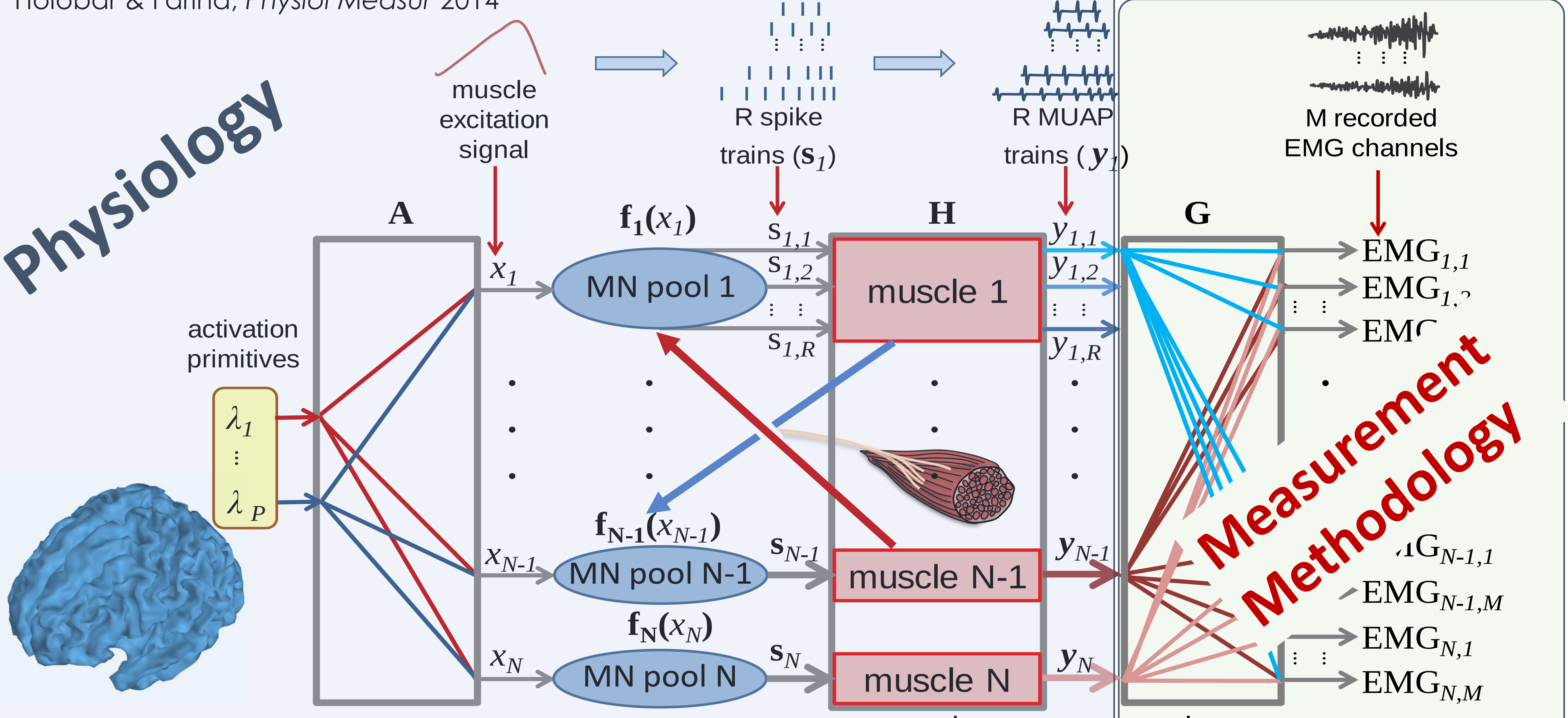
Holobar & Farina: IEEE Sig. Proc. Magazine, 2021

Surface EMG mixing models: signal-based approach

Holobar & Farina, *Physiol Measur* 2014



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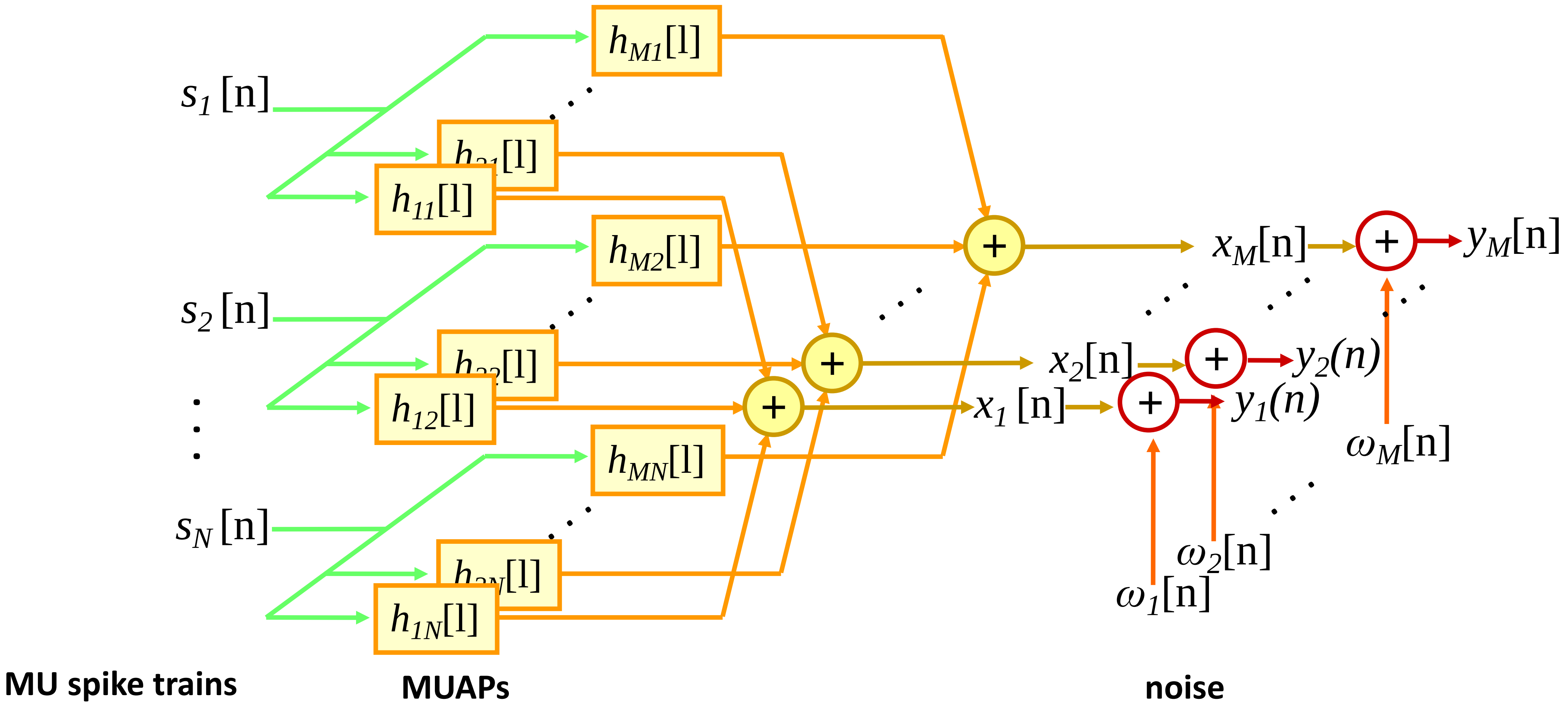
Isometric HDEMG model: Convolutive



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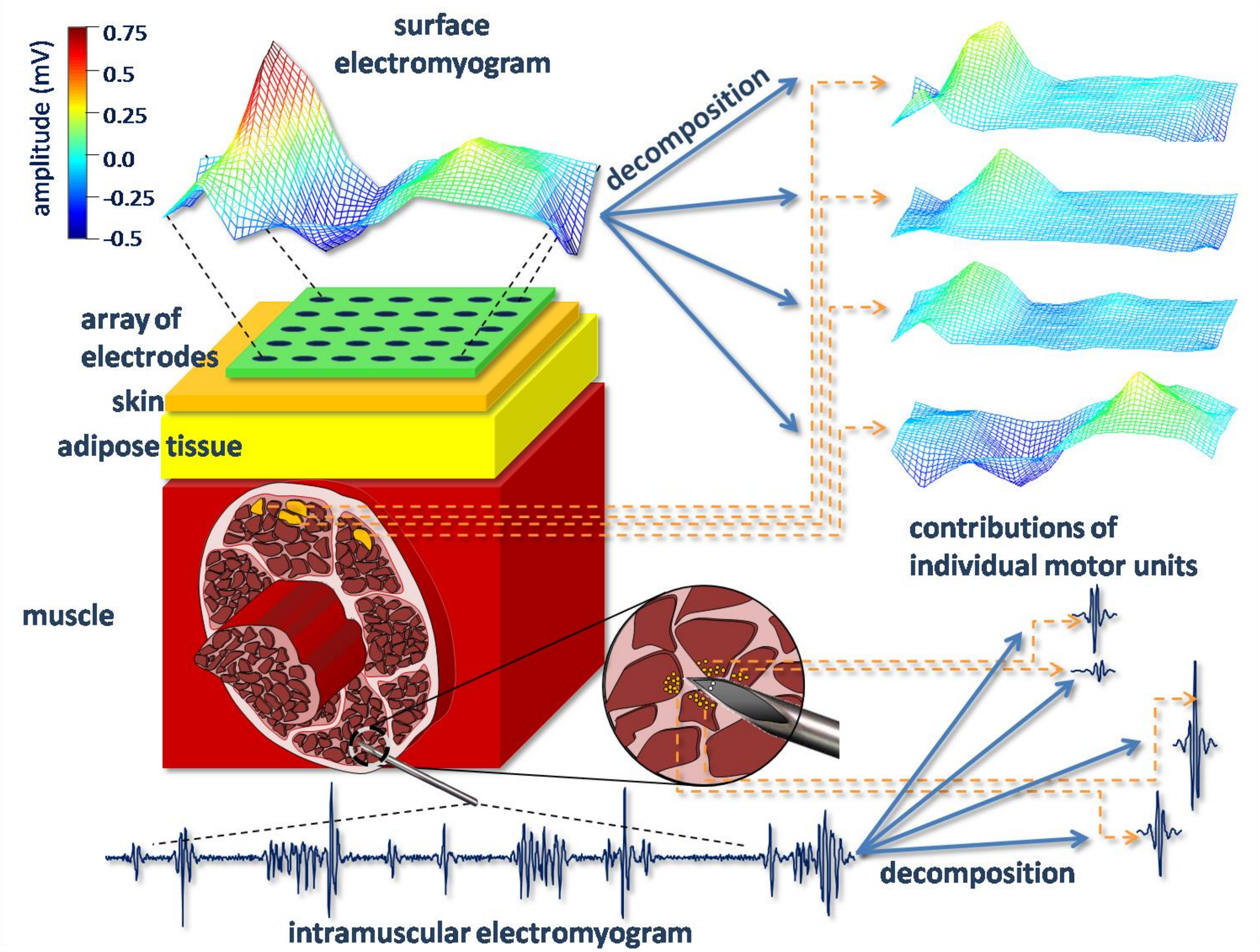
Intramuscular vs. surface EMG

- **Surface EMG**: 0-500 Hz, several tens of MUs
- **Intramuscular EMG**: 0-5000 Hz, low number of MUs
- **Surface MUAPs**: smooth (low-frequency) & longer (15 ms)
- **Intramuscular MUAPs**: sharper & shorter (5 ms)



Merletti et al. Critical Reviews in Biomedical Engineering, 2010

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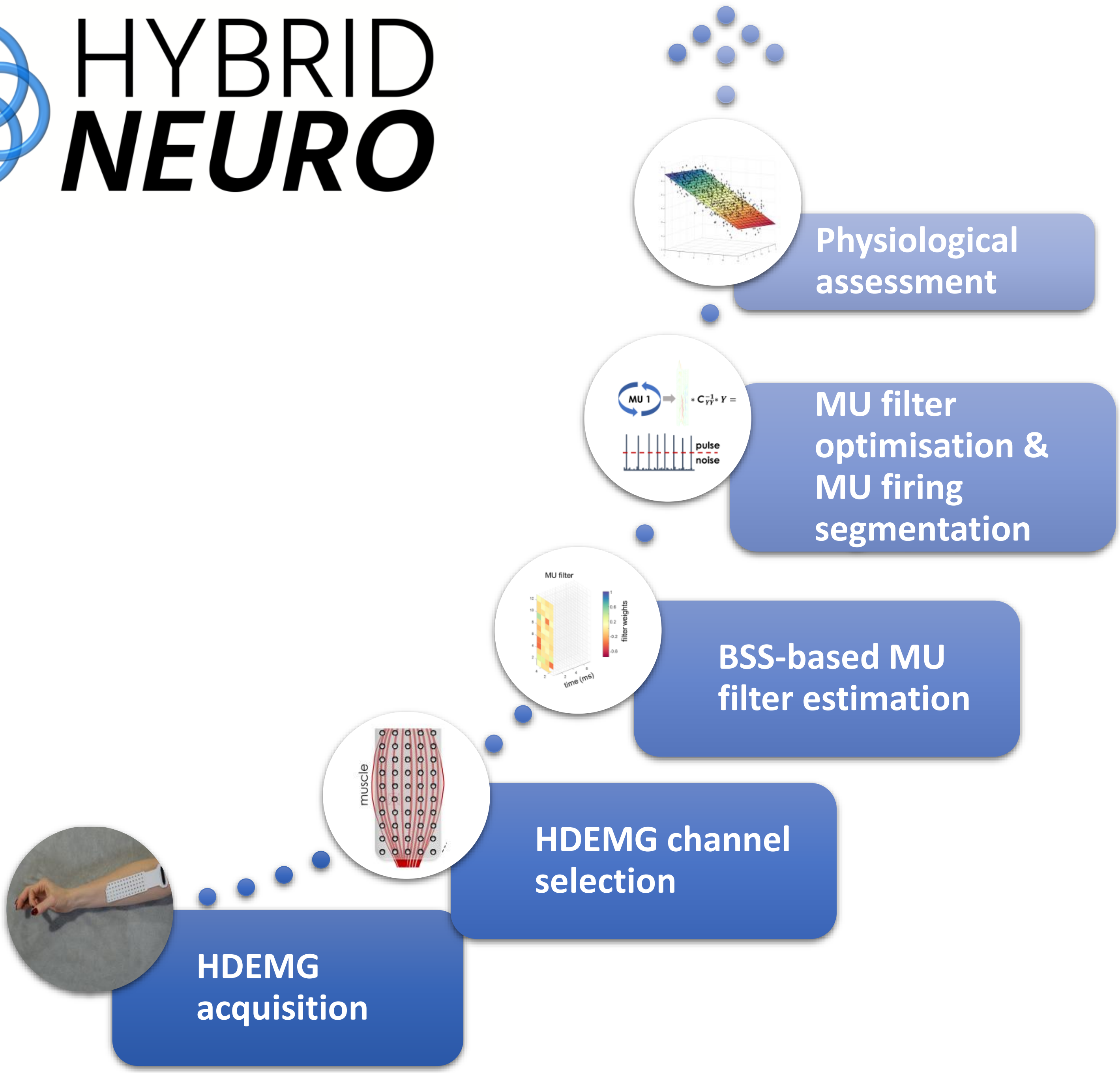
Processing pipelines

Know-how & details matter



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Isometric voluntary contractions – surface HDEMG

Asynchronous MU firings, stationary MUAPs

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MUAPs, MUs & EMG

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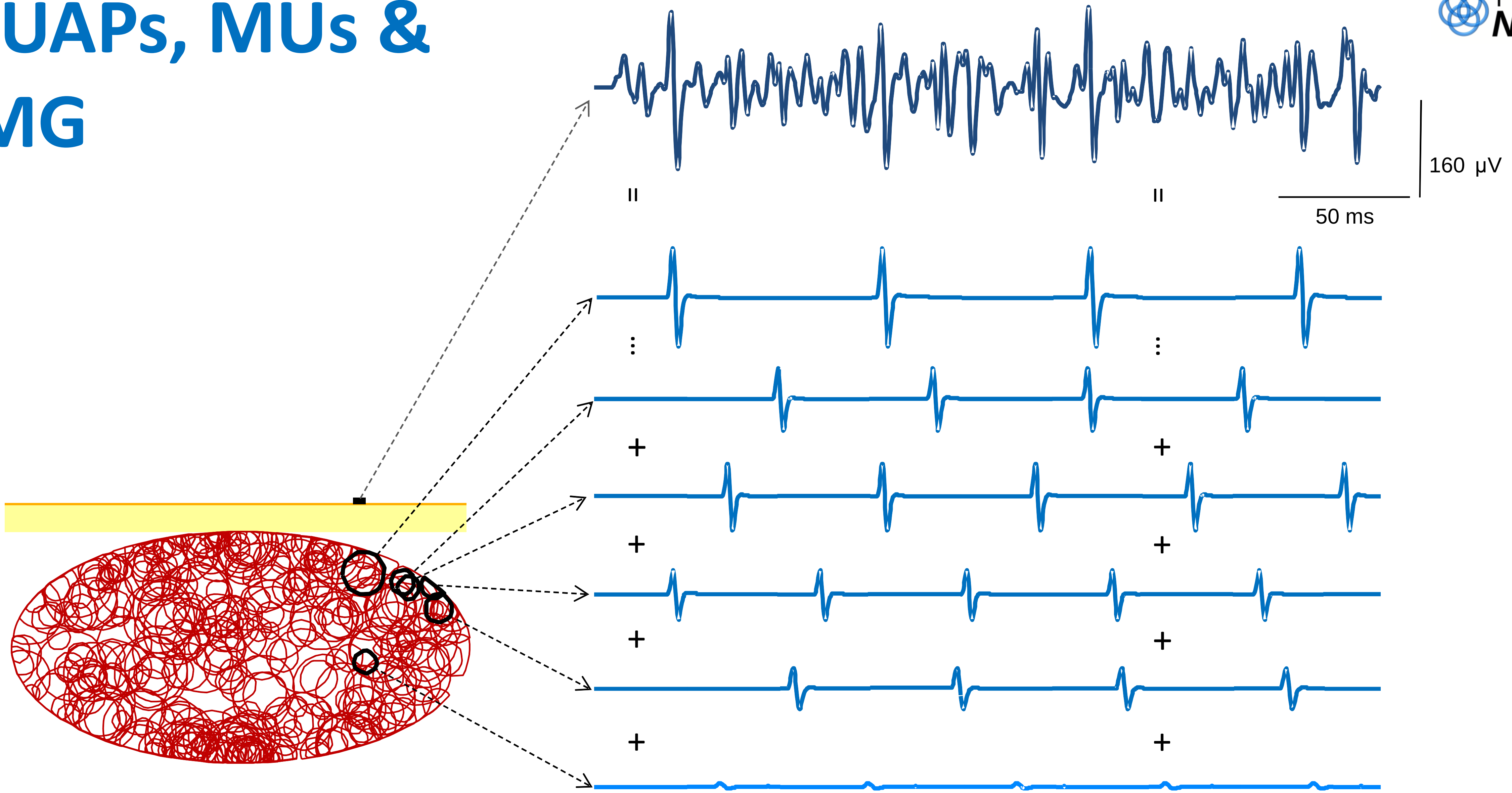

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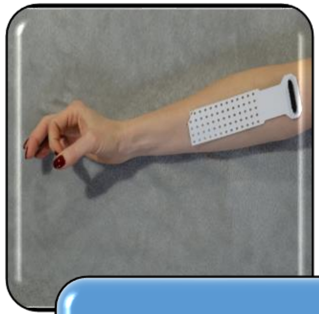
Holobar & Farina: Physiological Measurement, 2014

Processing pipeline

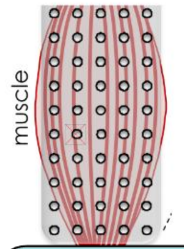
Segment
A



HDEMG acquisition

5 steps

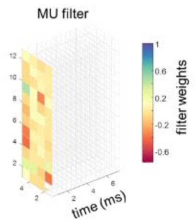
Segment
B



HDEMG channel selection

5 steps

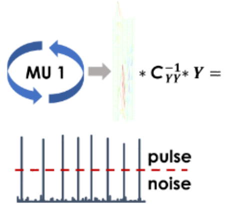
Segment
C



BSS-based MU filter estimation

5 steps

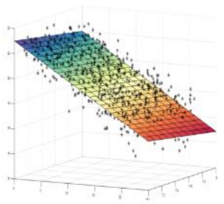
Segment
D



MU filter optimization & firings segmentation

5 steps

Segment
E



Physiological assessment

5 steps

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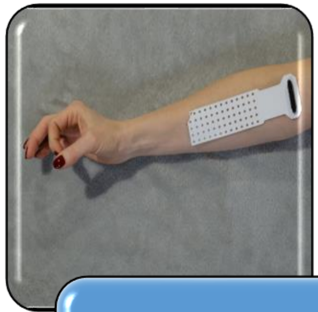
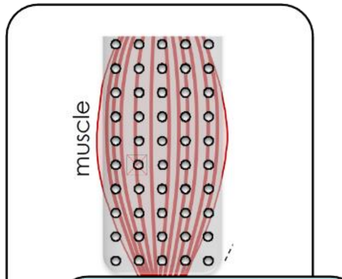
Processing pipeline: Segment A

HYBRID NEURO

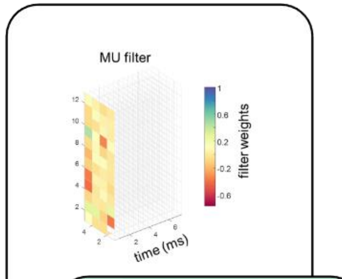
A



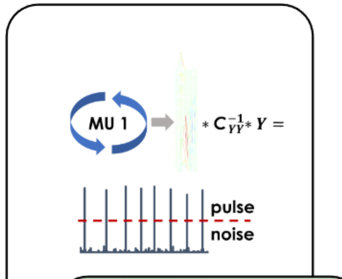
B



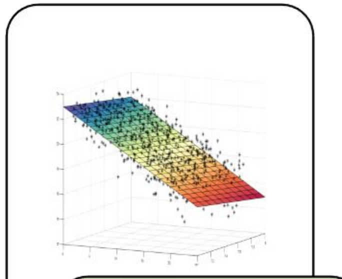
C



D



E



HDEMG acquisition → **HDEMG channel selection** → **BSS-based MU filter estimation** → **MU filter optimization & firing segmentation** → **Physiological assessment**

A1

Skin preparation

A2

Electrode preparation

A3

Electrode fixation

A4

Cable fixation & many little tricks

A5

Repeat some of the previous steps if needed

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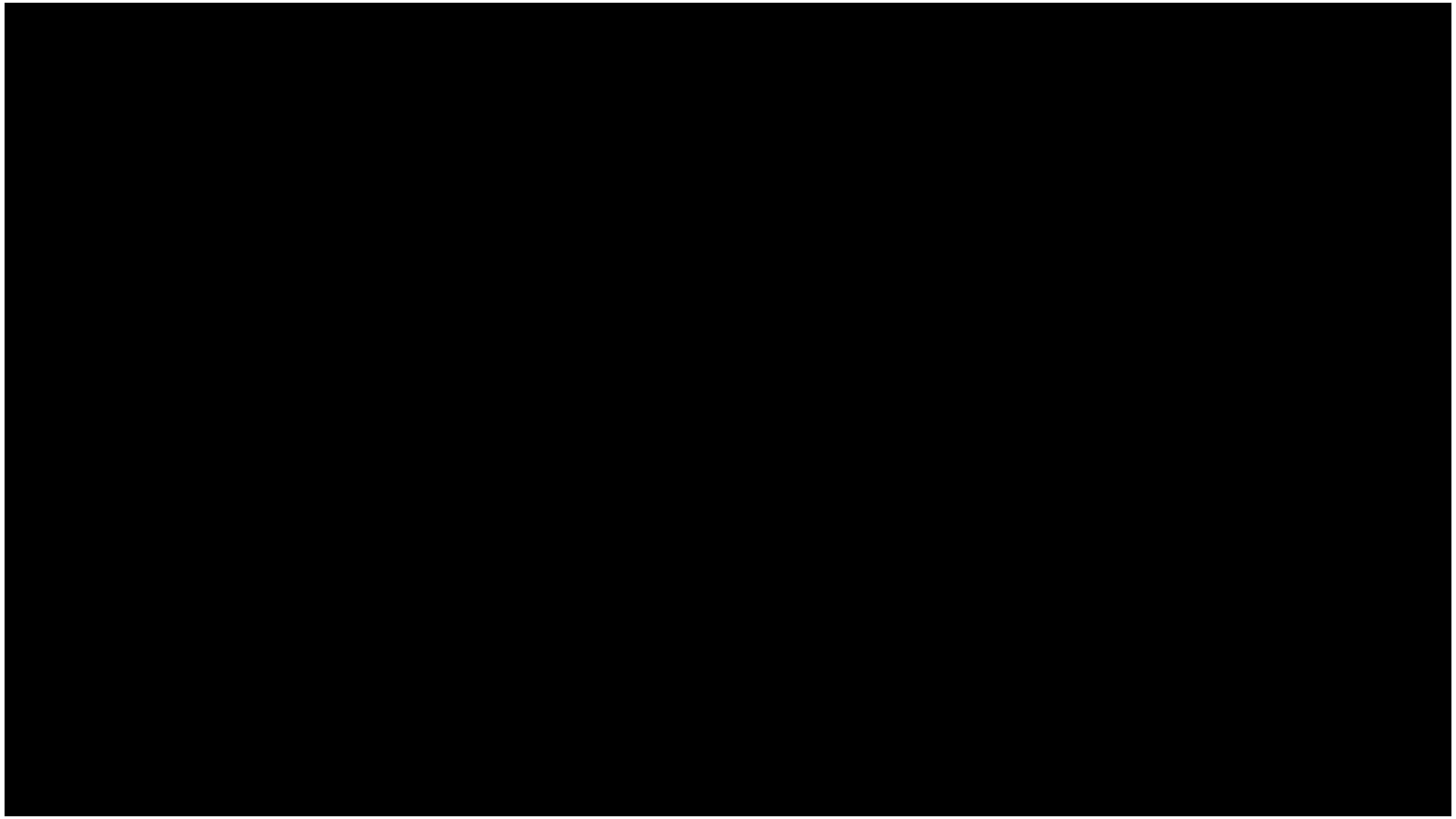
HDEMG acquisition – electrode fixation



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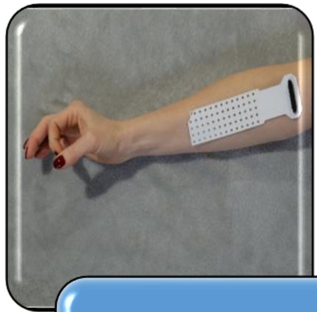
Processing pipeline

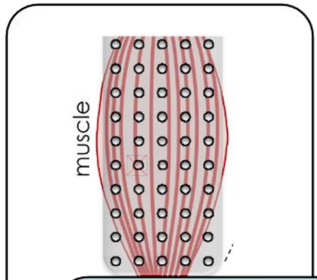
Segment A



HDEMG acquisition

5 steps

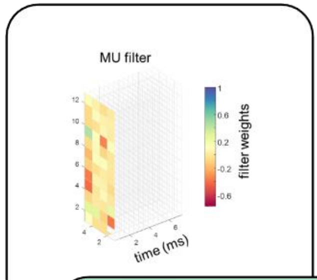
Segment B



HDEMG channel selection

5 steps

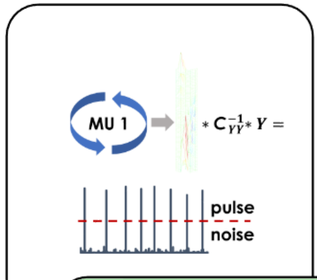
Segment C



BSS-based MU filter estimation

5 steps

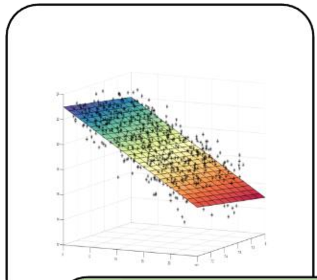
Segment D



MU filter optimization & firings segmentation

5 steps

Segment E



Physiological assessment

5 steps

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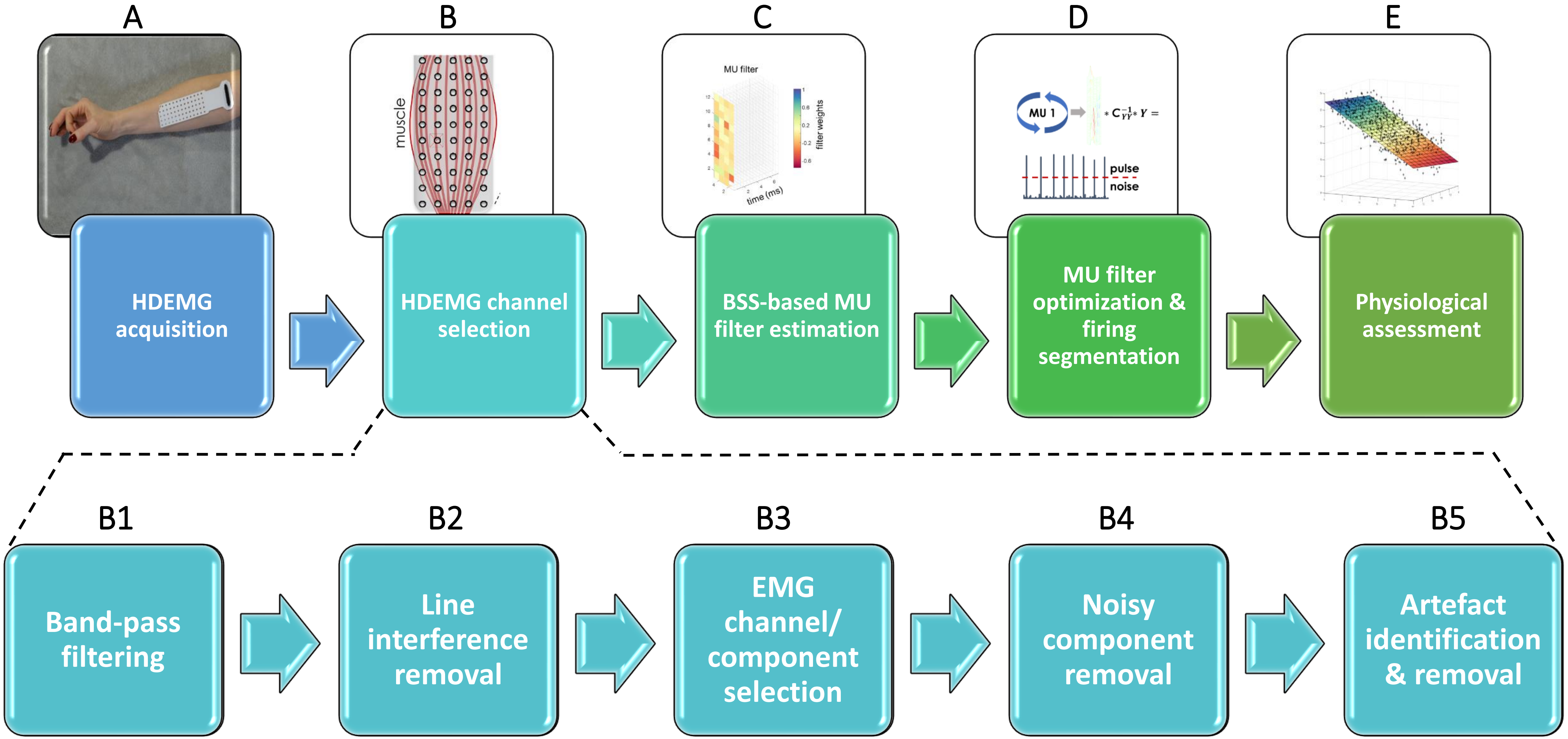
Processing pipeline: Segment B



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Nonlinear transformations of EMG are forbidden

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- Nonlinear transformations are forbidden!
  - They destroy the linear superimposition of MUAPs (i.e. linear mixing model)
- Nonlinear transformations are forbidden!
  - They introduce additional crossterms (i.e., cross spike trains between any pair of active MUs)
  - $(\boldsymbol{a}+\boldsymbol{b})^{2} \neq \boldsymbol{a}^{2}+\boldsymbol{b}^{2}$
  - $\boldsymbol{a}$ - spike train 1
  - $\boldsymbol{b}$ - spike train 2
  - $\boldsymbol{2ab}$- crossterm between spike train 1 and 2
- Nonlinear transformations are really bad idea!
- And they are forbidden!

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B2 - Line interference: zero-phase filtering or…

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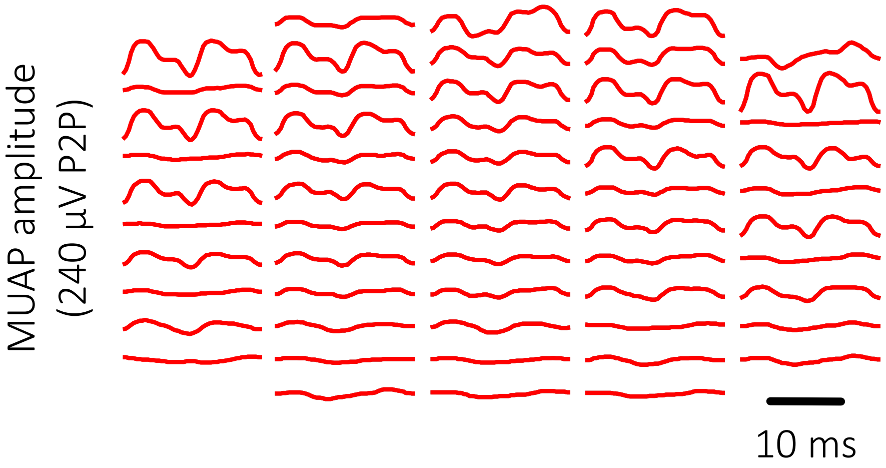
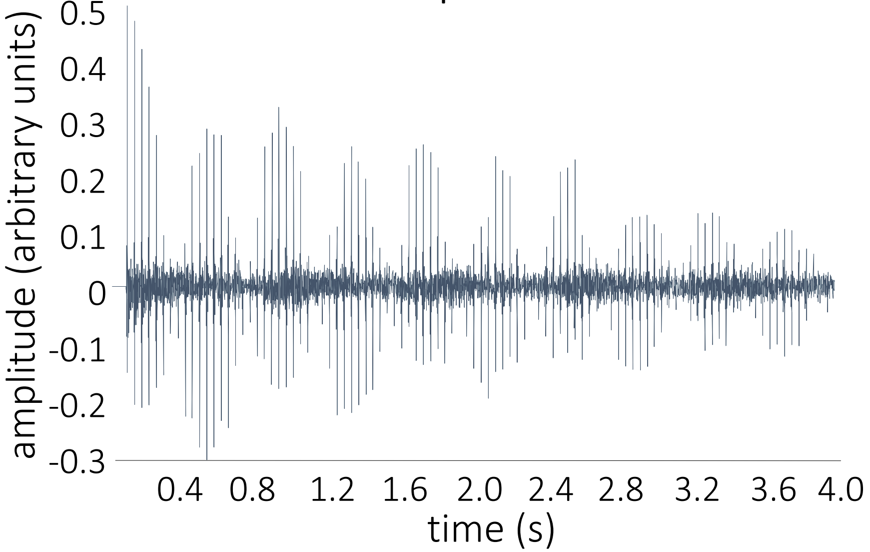
MUAP shapes

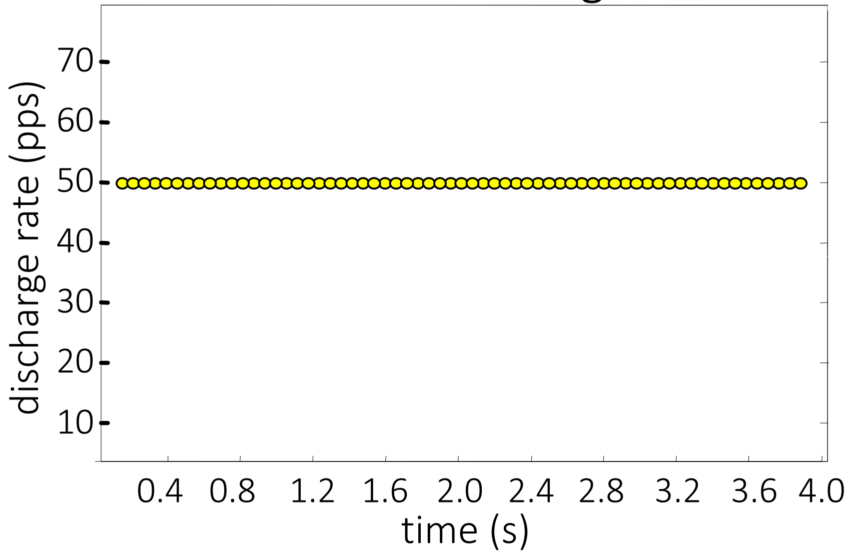


innervation pulse train

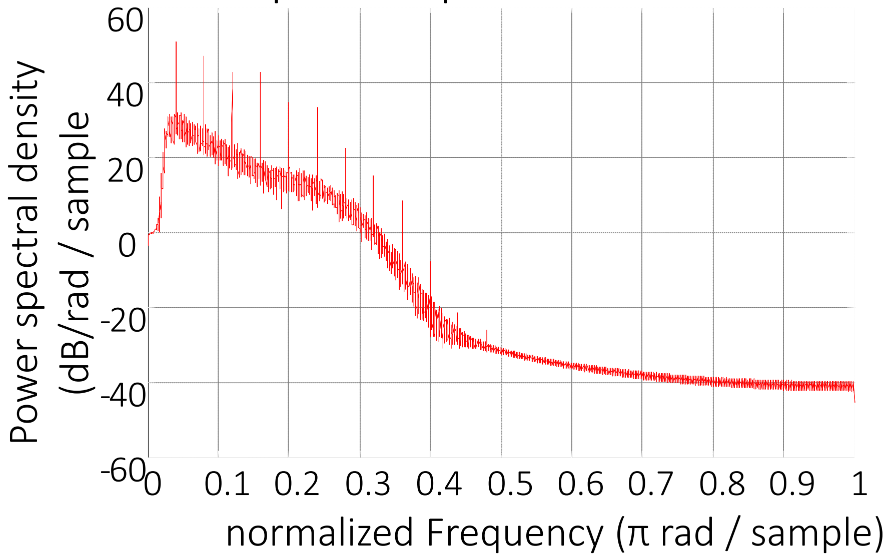


Avoid nonlinear techniques in filtering or preprocessing!

instantaneous discharge rate



power spectrum



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B3 – EMG channels (VL muscle)

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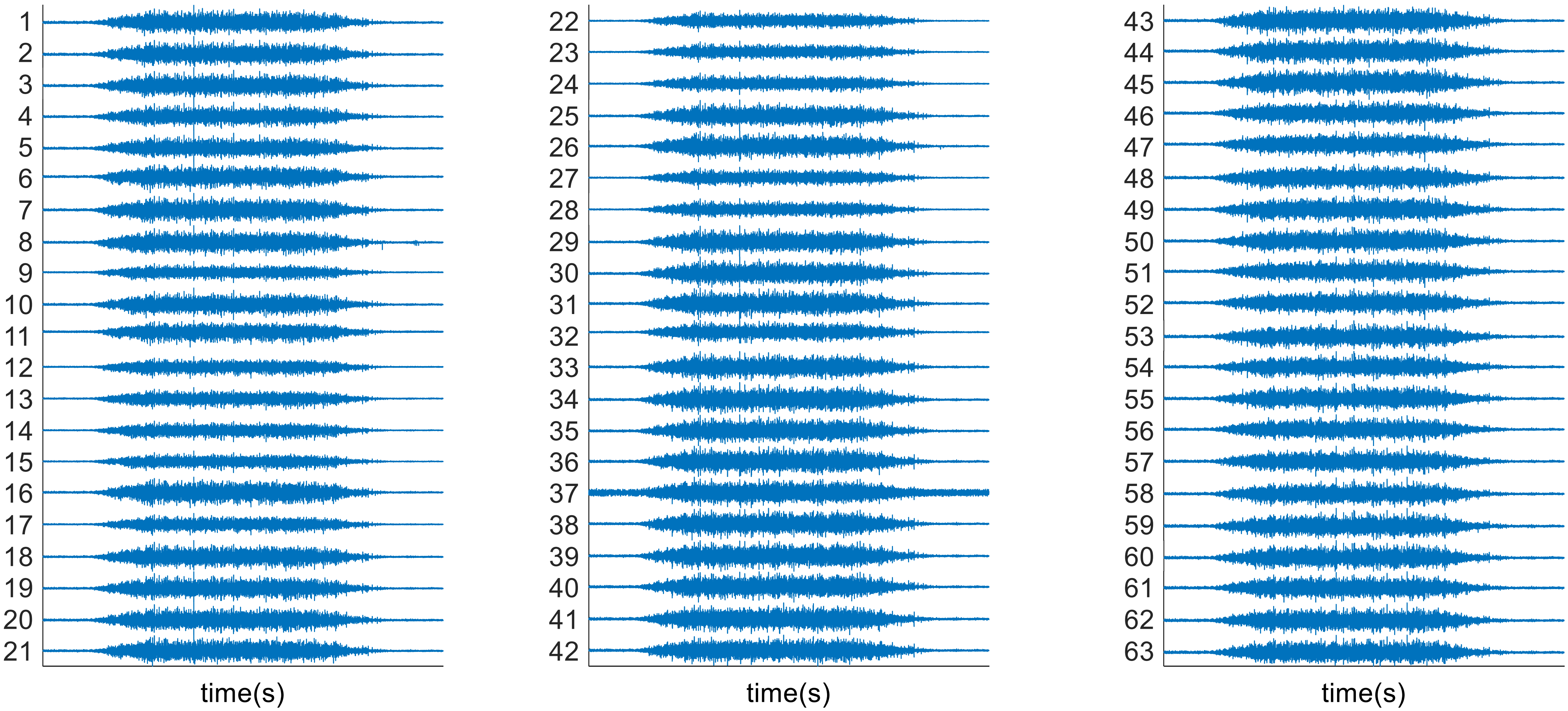

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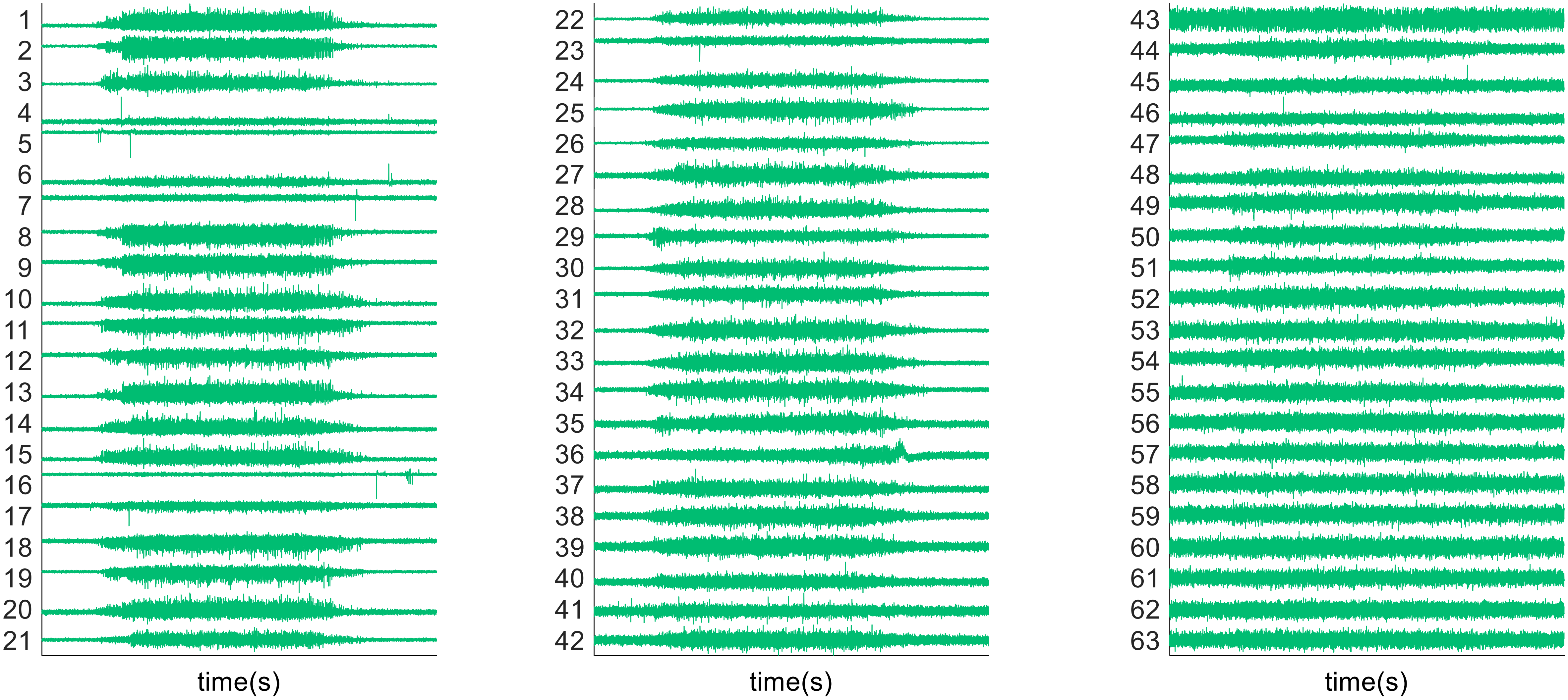
B1 – ICA components (VL muscle)



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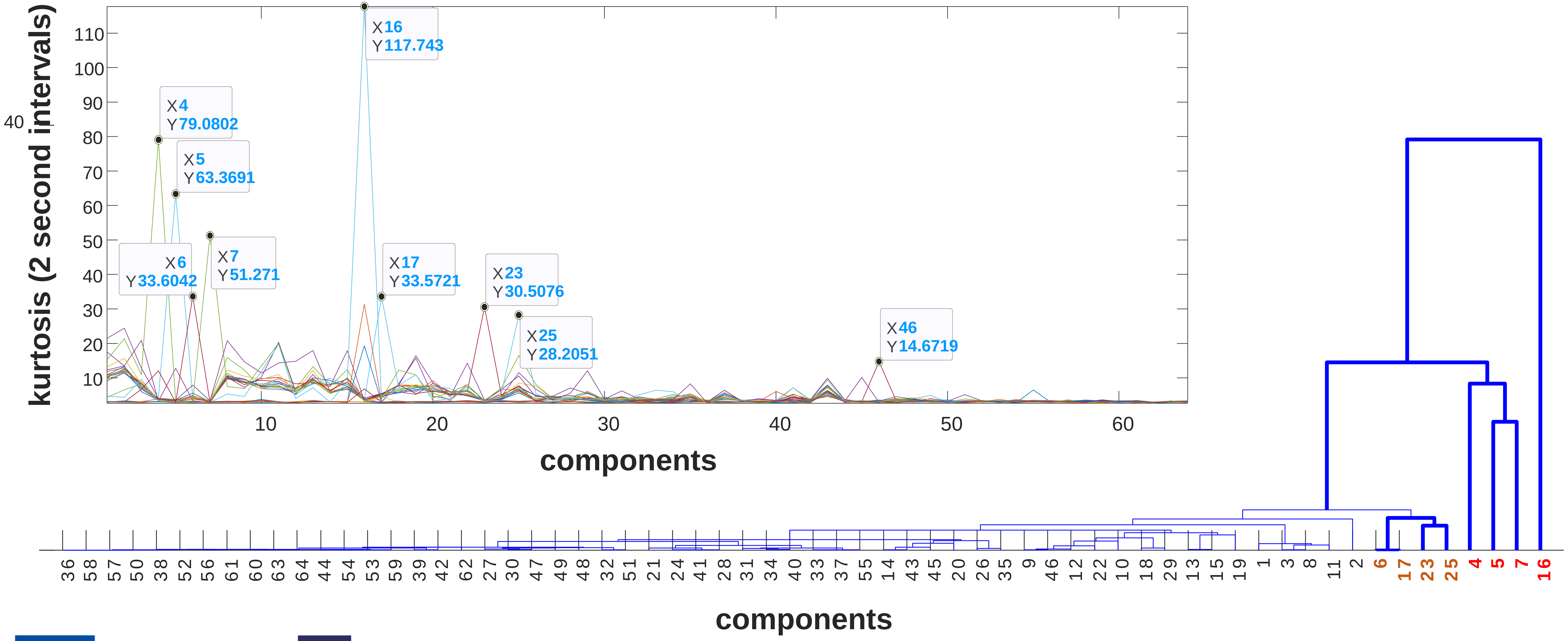
B2 – Noisy component removal



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B2 – Noisy component removal

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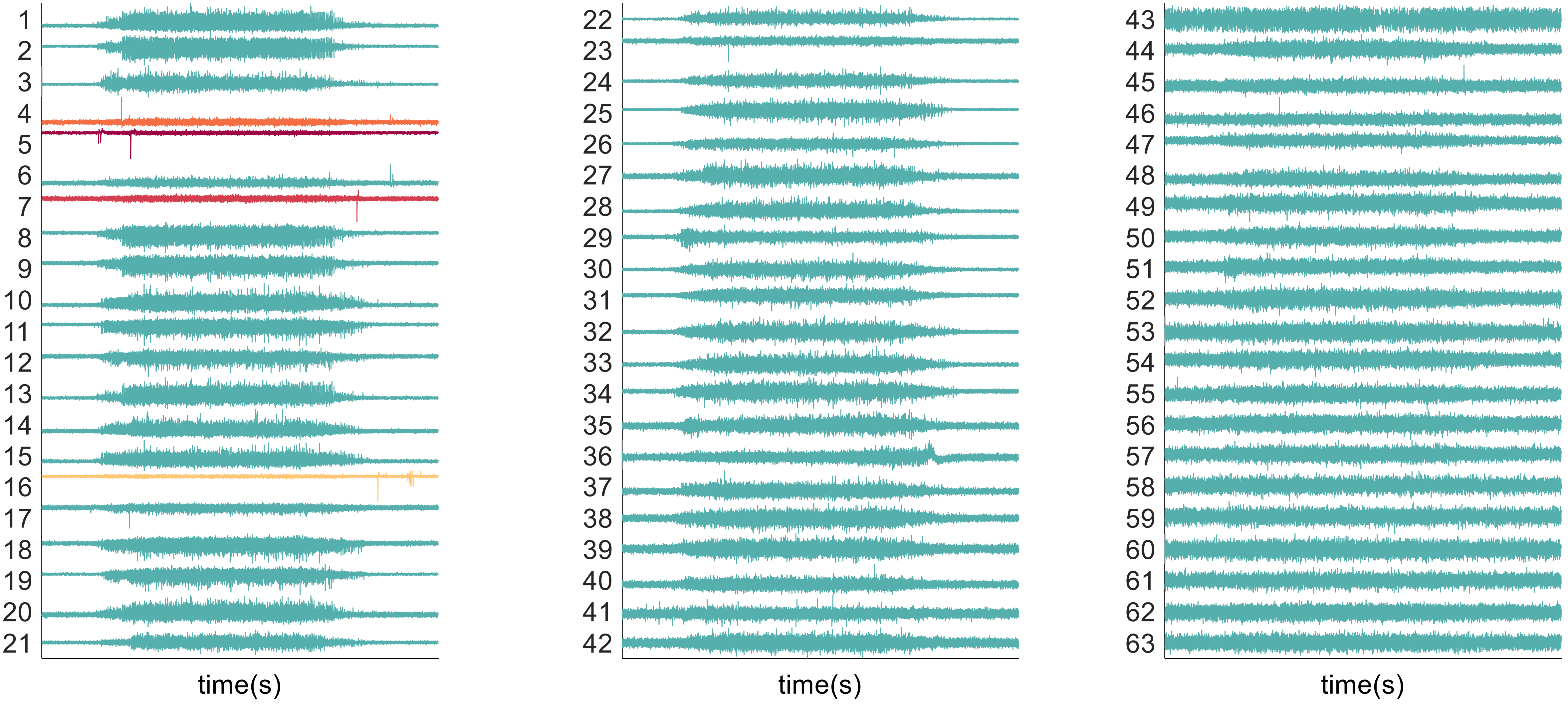

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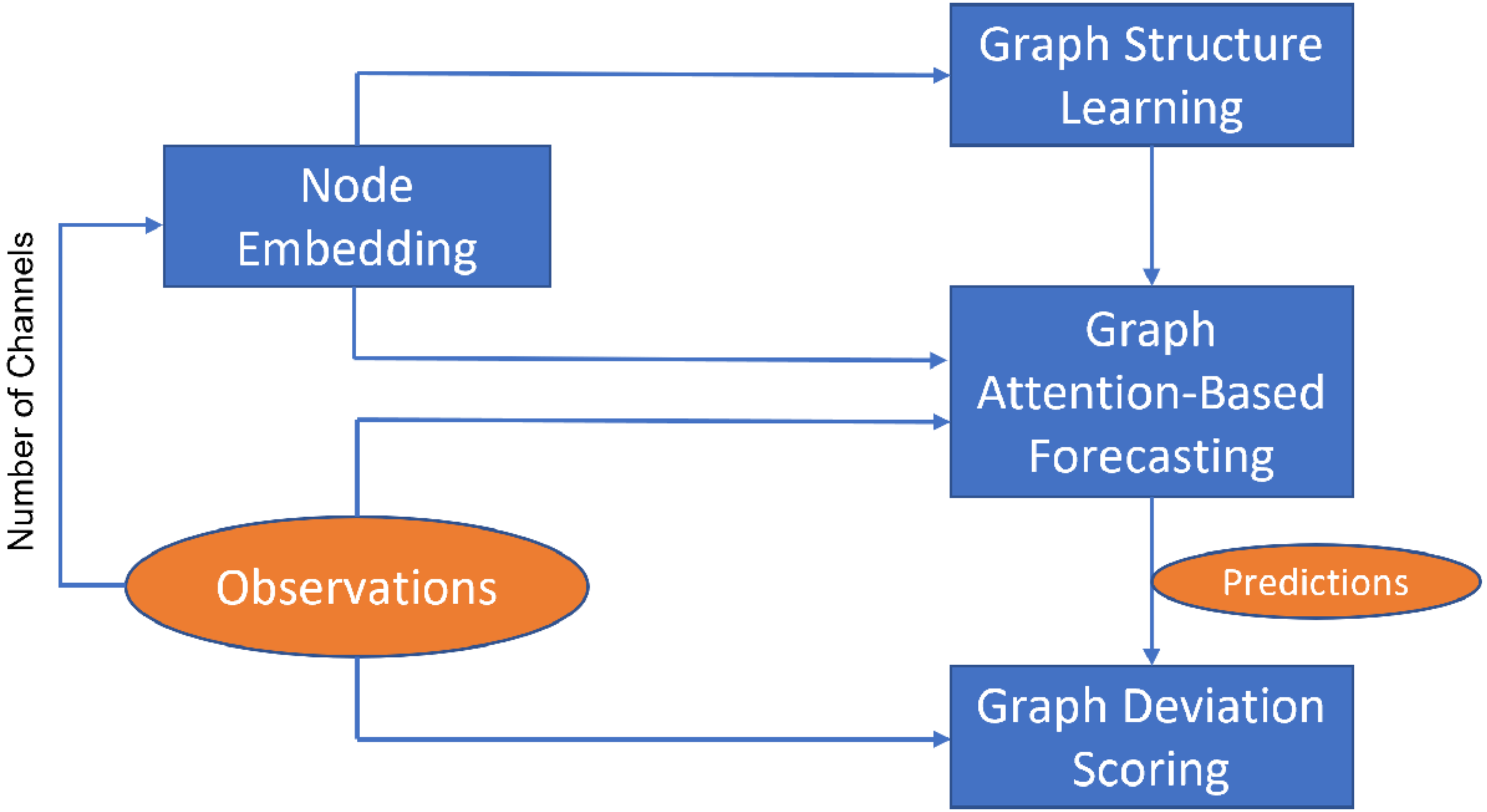
B3 – Artefact removal: Multivariate Time Series Anomaly Detection Using Graph Neural Network (MATLAB)



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https://www.mathworks.com/help/deeplearning/ug/multivariate-time-series-anomaly-detection-using-graph-neural-network.html

B3 – Artefact removal

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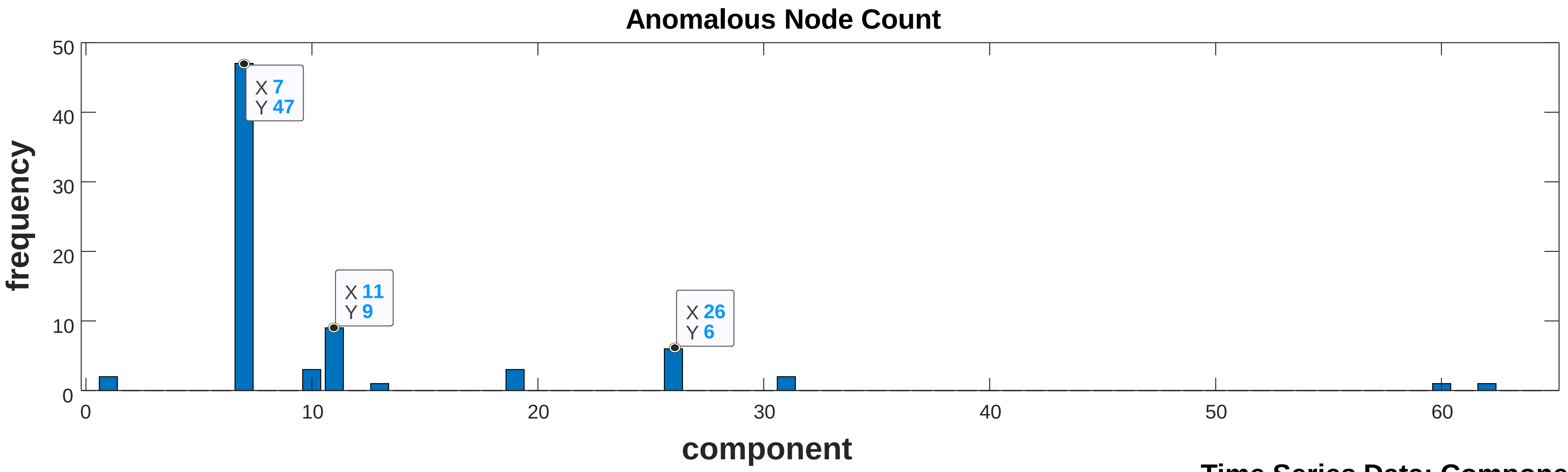

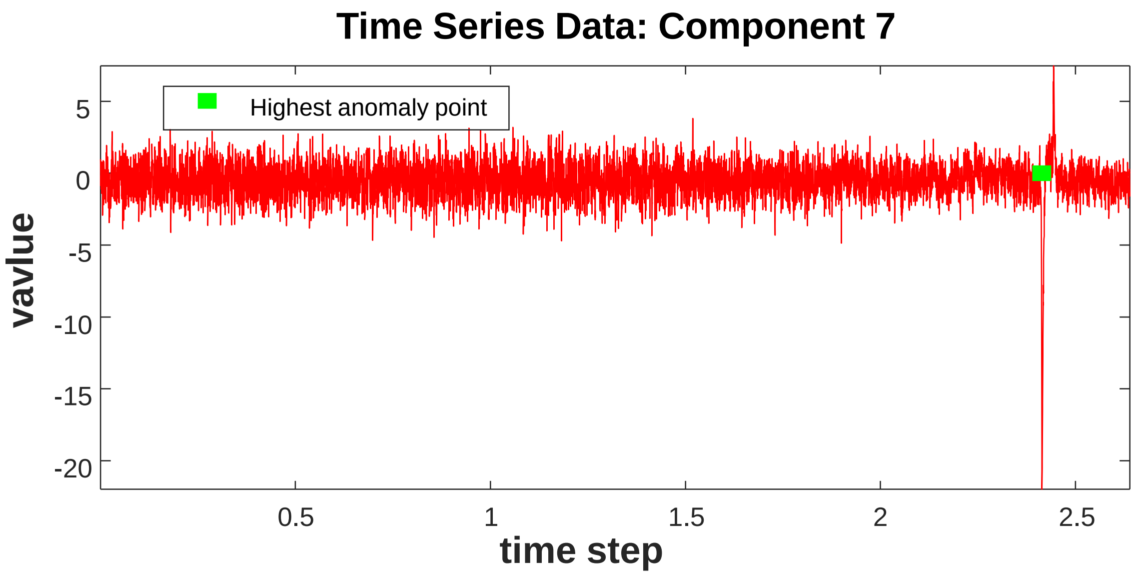

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Processing pipeline

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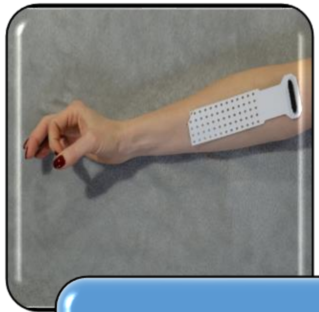
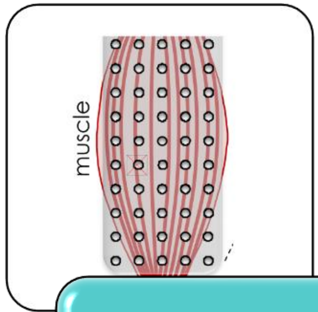
Segment A



HDEMG acquisition

5 steps

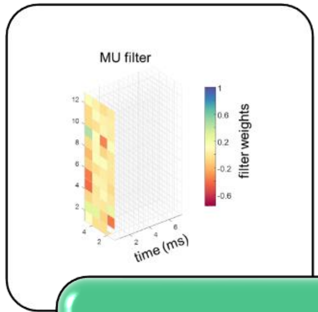
Segment B



HDEMG channel selection

5 steps

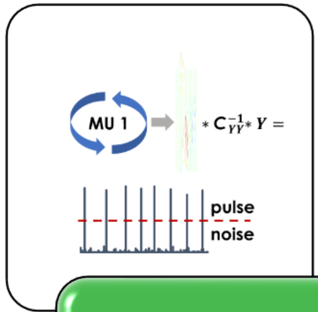
Segment C



BSS-based MU filter estimation

5 steps

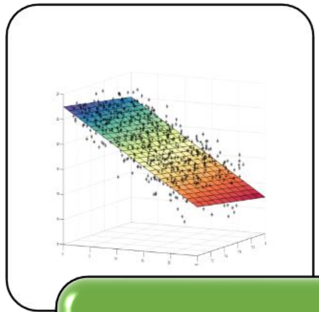
Segment D



MU filter optimization & firings segmentation

5 steps

Segment E



Physiological assessment

5 steps

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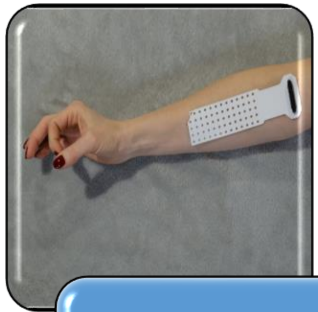
Processing pipeline: Segment C

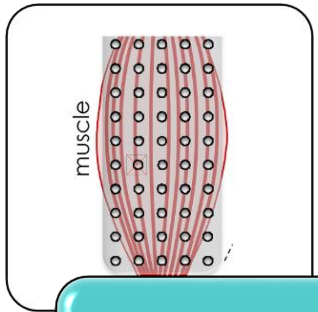
HYBRID NEURO

A



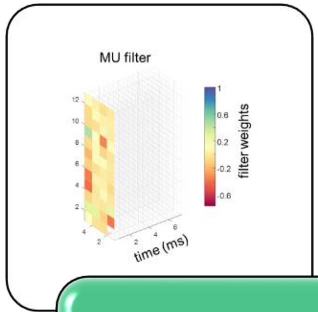
HDEMG quality control

B



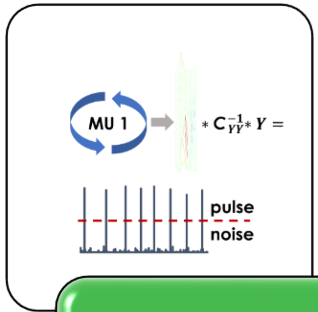
HDEMG channel selection

C



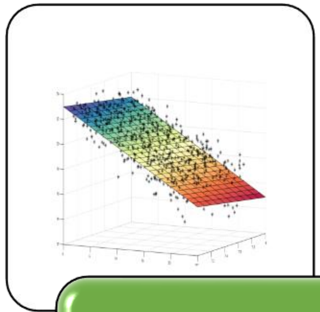
BSS-based MU filter estimation

D



MU filter optimization & firing segmentation

E



Physiological assessment

C1

Extension

C2

Dimension reduction

C3

BSS-based MU filter estimation

C4

Accuracy assessment

C5

Bad MU removal

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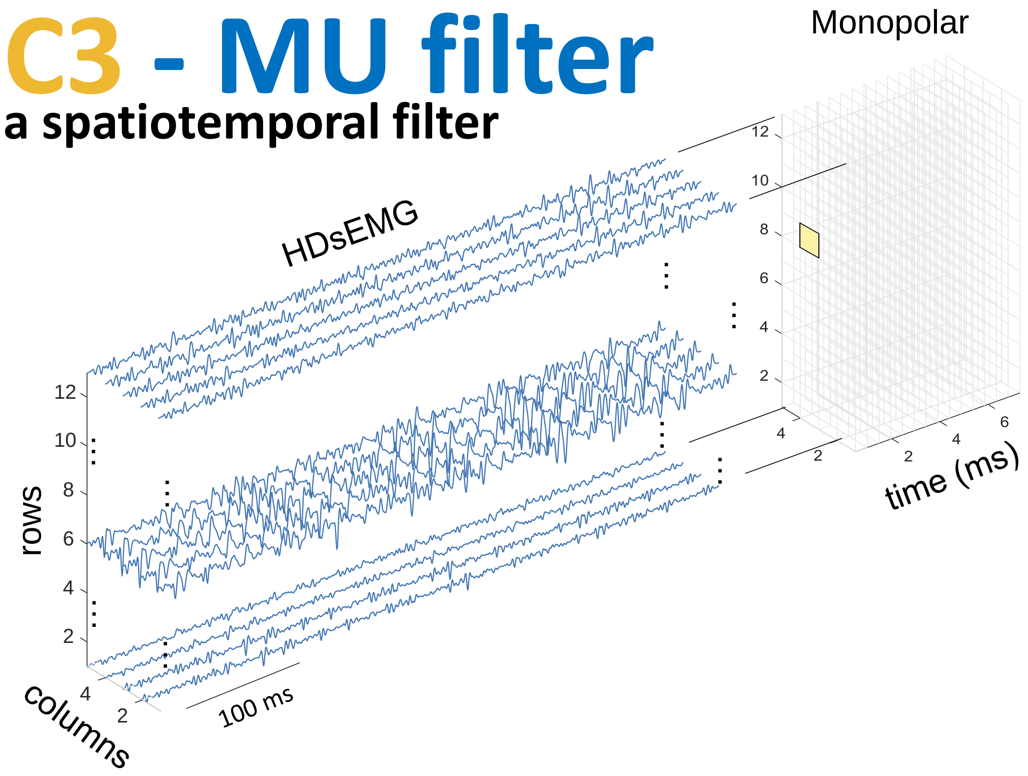
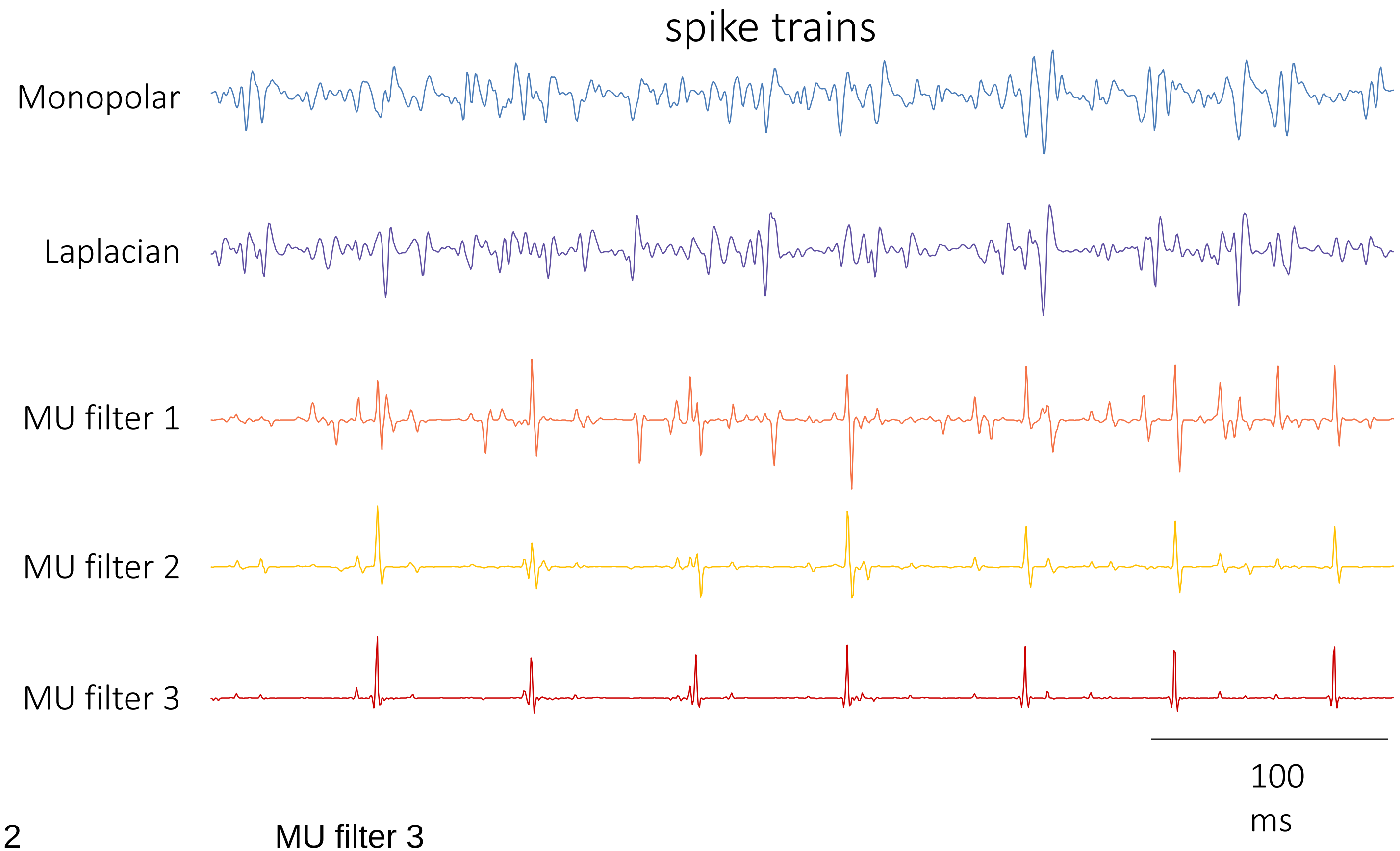
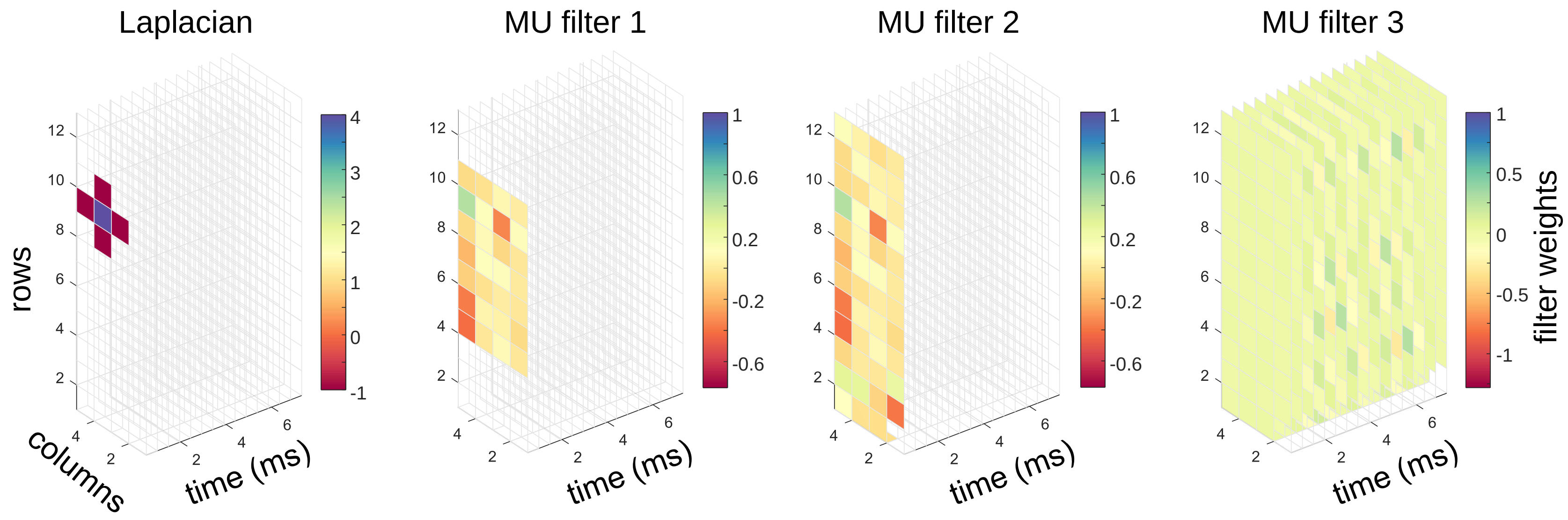
C3 - MU filter

a spatiotemporal filter







Škarabot et al. The Journal of Physiology, 2023

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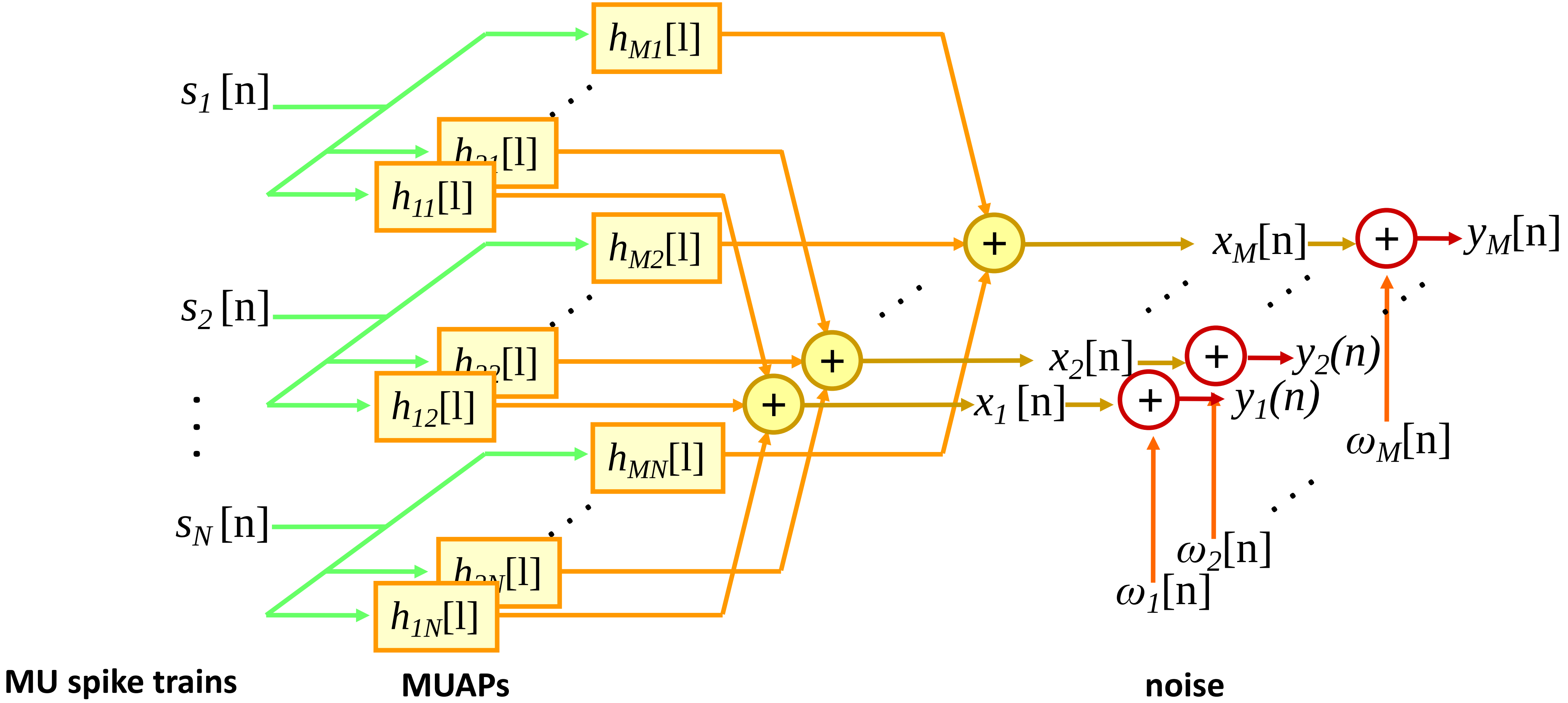
Isometric HDEMG model: Convolutive



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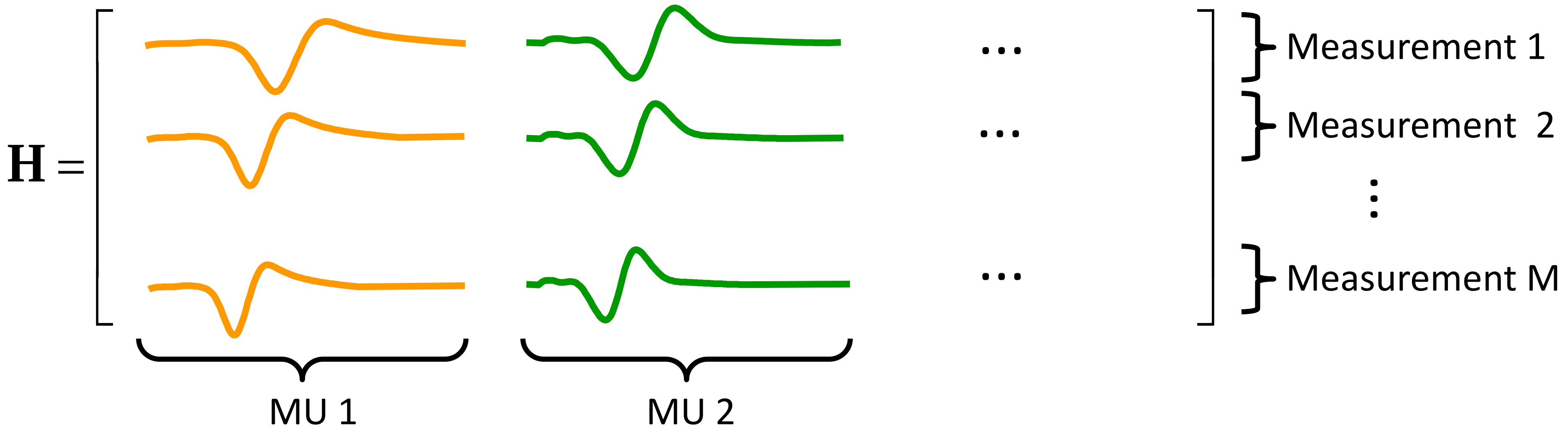
Data model: matrix form

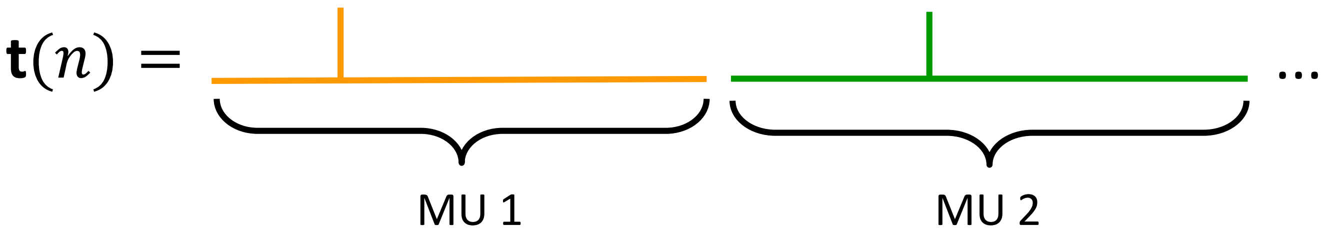
$$\boxed{y(n) = \mathbf{Ht}(\mathbf{n}) + \boldsymbol{\omega}(\mathbf{n})}$$

noise

- **Mixing matrix of convolution kernels (MUAPs):**



- **Extended vector of pulse sources:**



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Convolution Kernel Compensation (CKC)

hdEMG model: $\mathbf{y}(n) = \mathbf{H}\mathbf{t}(n) + \boldsymbol{\omega}(n)$

MU spike trains: $t_{\mathrm{j}}(\mathrm{n}) = \sum_{\mathrm{k}} \delta\left(n - \tau_{\mathrm{j}}(k)\right)$, $j=1...N$

MUAPs: $\overline{\mathbf{H}} = [\overline{\mathbf{H}_1} \dots \overline{\mathbf{H}_\mathrm{N}}]$

$$\overline{\mathbf{H}_j} = \begin{bmatrix} \overline{h_{1\mathrm{j}}}(0) & \dots & \overline{h_{1\mathrm{j}}}(L) \\ \vdots & \ddots & \vdots \\ \overline{h_{\mathrm{Mj}}}(0) & \dots & \overline{h_{\mathrm{Mj}}}(L) \end{bmatrix}$$

CKC: $\hat{t}_j(n) = \mathbf{c}_{\mathrm{t_j y}}^{\mathrm{T}} \mathbf{C}_{\mathbf{y}}^{-1} \mathbf{y}(n) = \mathbf{c}_{\mathrm{t_j t}}^{\mathrm{T}} \boxed{\mathbf{H}^{\mathrm{T}} \mathbf{H}^{-\mathrm{T}}} \mathbf{C}_{\mathbf{t}}^{-1} \boxed{\mathbf{H}\mathbf{H}^{-1}} \mathbf{t}(n) \approx \mathbf{c}_{\mathrm{t_j t}}^{\mathrm{T}} \mathbf{C}_{\mathbf{t}}^{-1} \mathbf{t}(n)$

MU filter $\mathbf{c}_{\mathrm{t_j y}}^{\mathrm{T}} \mathbf{C}_{\mathbf{y}}^{-1}$ needs to be estimated for every motor unit

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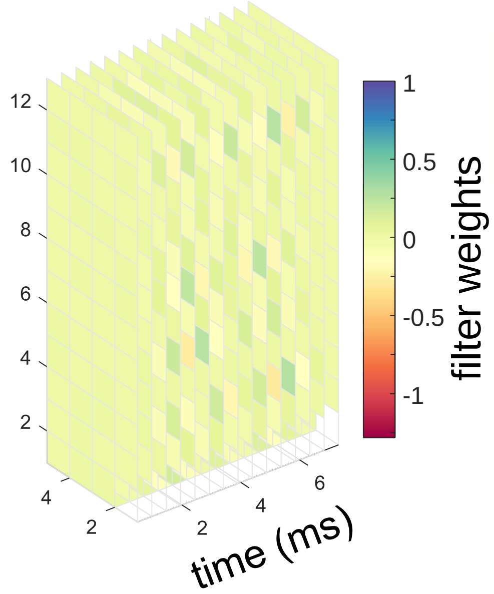
MU filter: MUAP viewpoint



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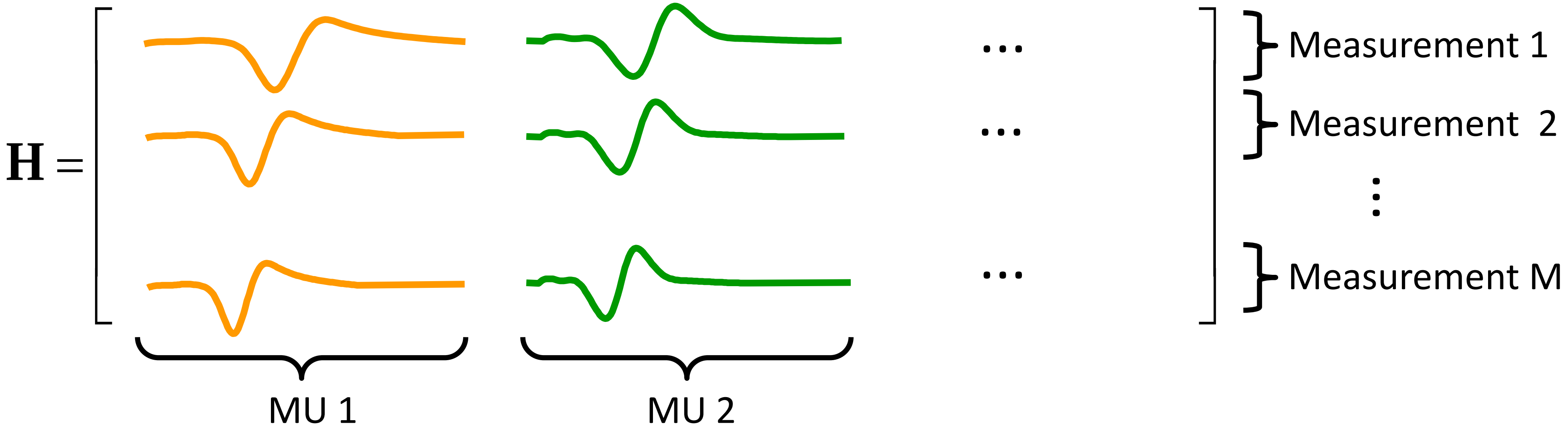
Large MU filter $\mathbf{c}_{\mathbf{t_j y}}^{\mathrm{T}} \mathbf{C}_{\mathbf{y}}^{-1}$

Portion of MUAPs considdered by $\mathbf{c}_{\mathbf{t_j y}}^{\mathrm{T}}$:



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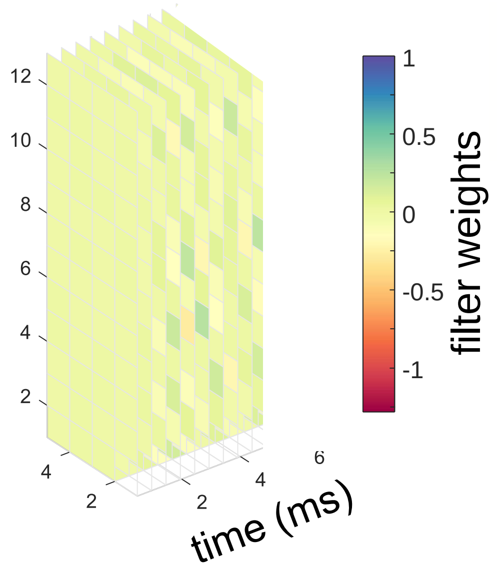
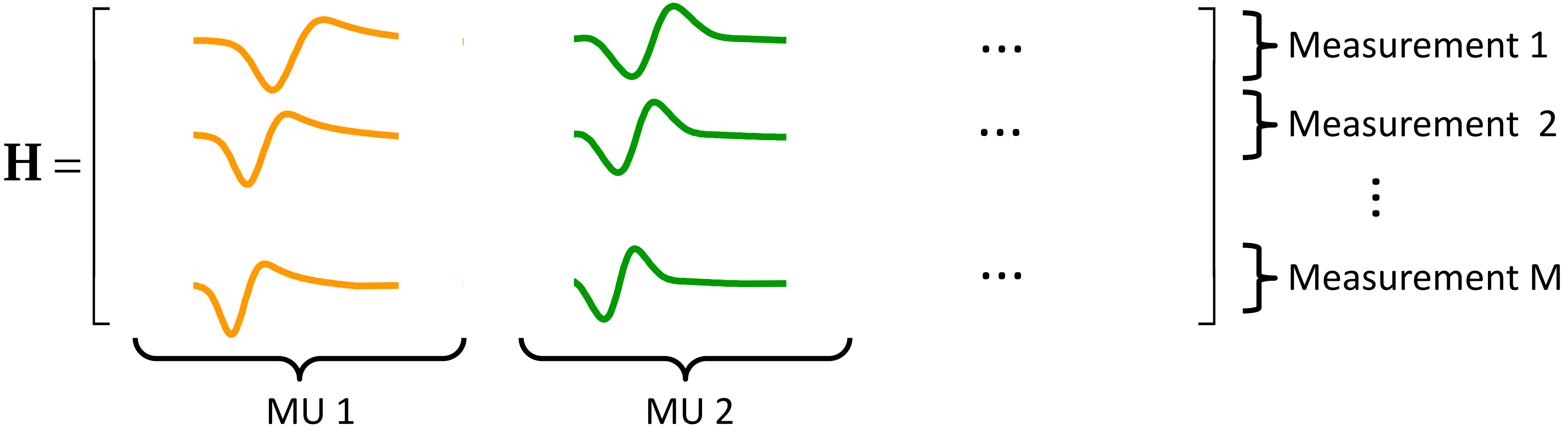
MU filter: MUAP viewpoint



Smaller MU filter $\mathbf{c}_{\mathbf{t_j y}}^{\mathbf{T}} \mathbf{C}_{\mathbf{y}}^{-1}$

Portion of MUAPs considdered by $\mathbf{c}_{\mathbf{t_j y}}^{\mathbf{T}}$:



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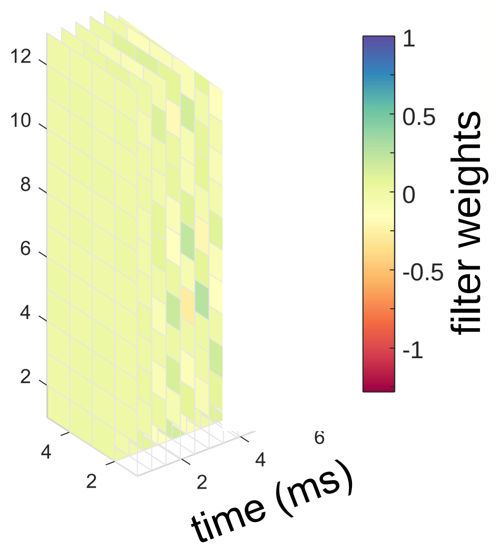
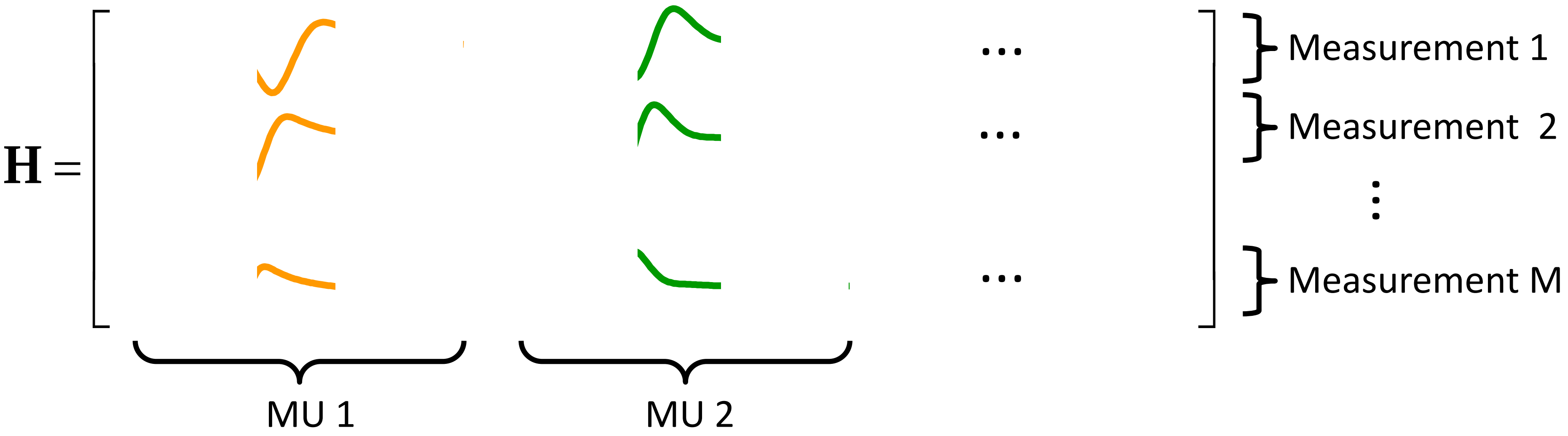
MU filter: MUAP viewpoint



Still smaller MU filter $\mathbf{c}_{t_j y}^T \mathbf{C}_y^{-1}$

Portion of MUAPs considdered by $\mathbf{c}_{t_j y}^T$:



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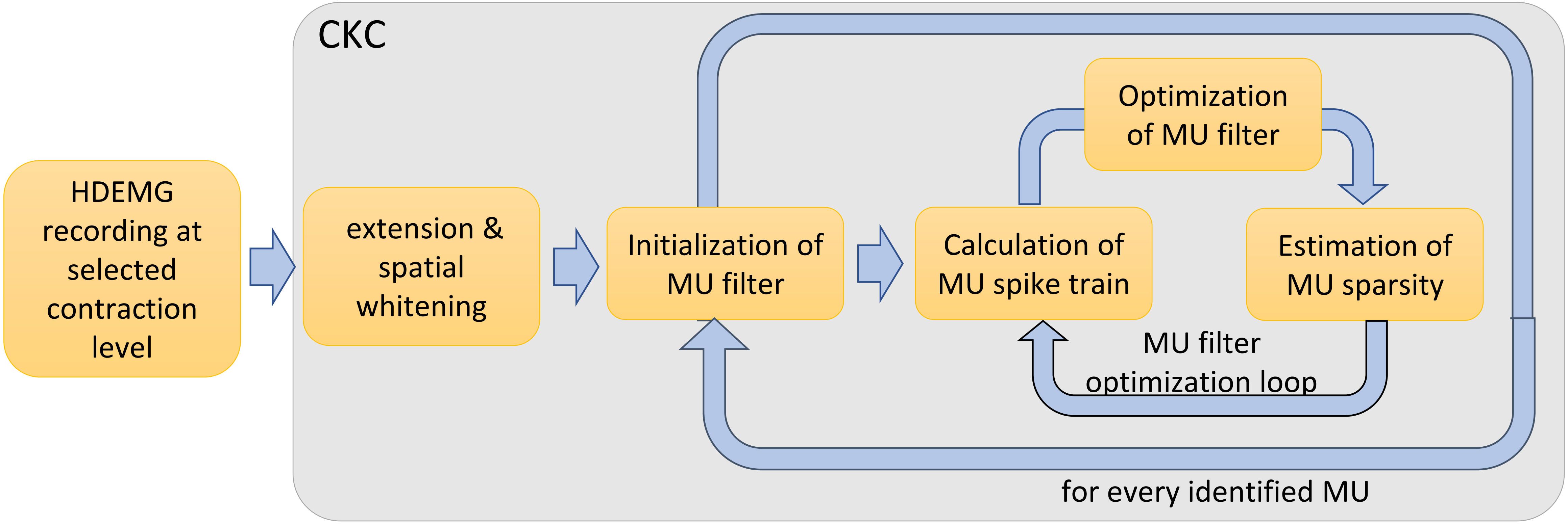
C3 – MU filter estimation



Škarabot et al. The Journal of Physiology, 2023

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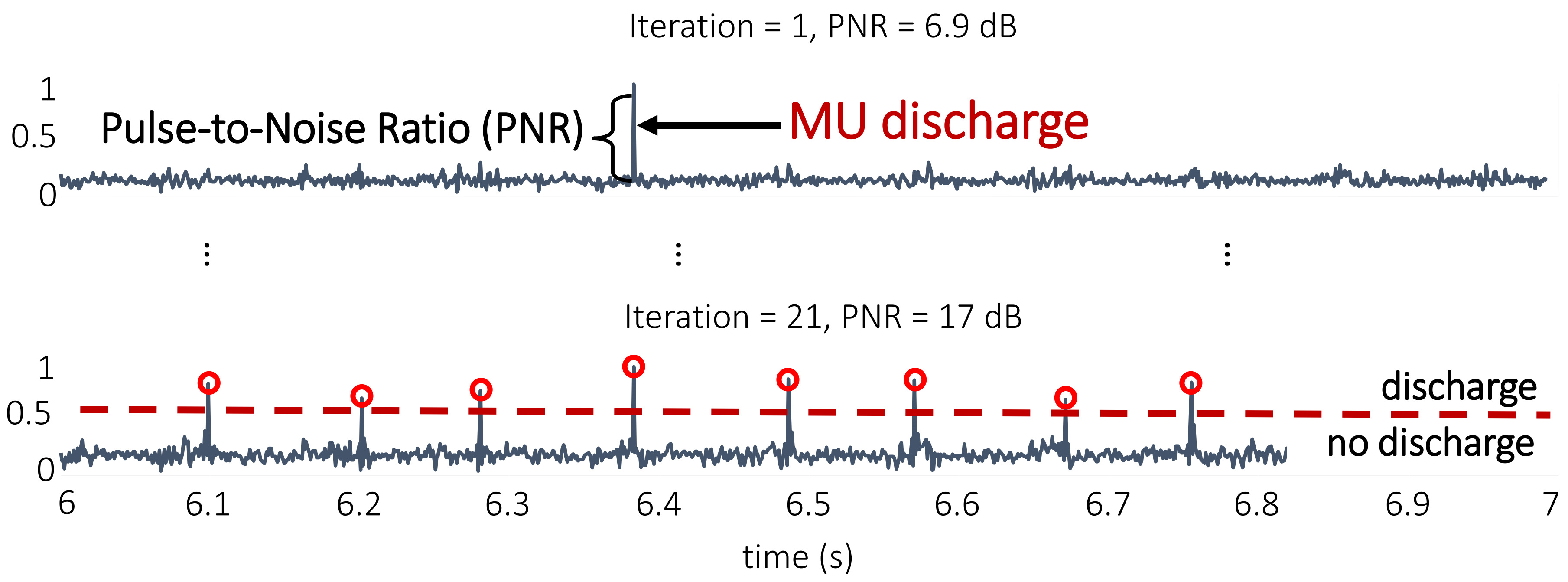
C4 – Accuracy assessment: PNR

HYBRID NEURO



Pulse-to-Noise Ratio (PNR):

- applied to EVERY identified motor unit
- no additional experimental costs
- indicator of the accuracy of motor unit identification

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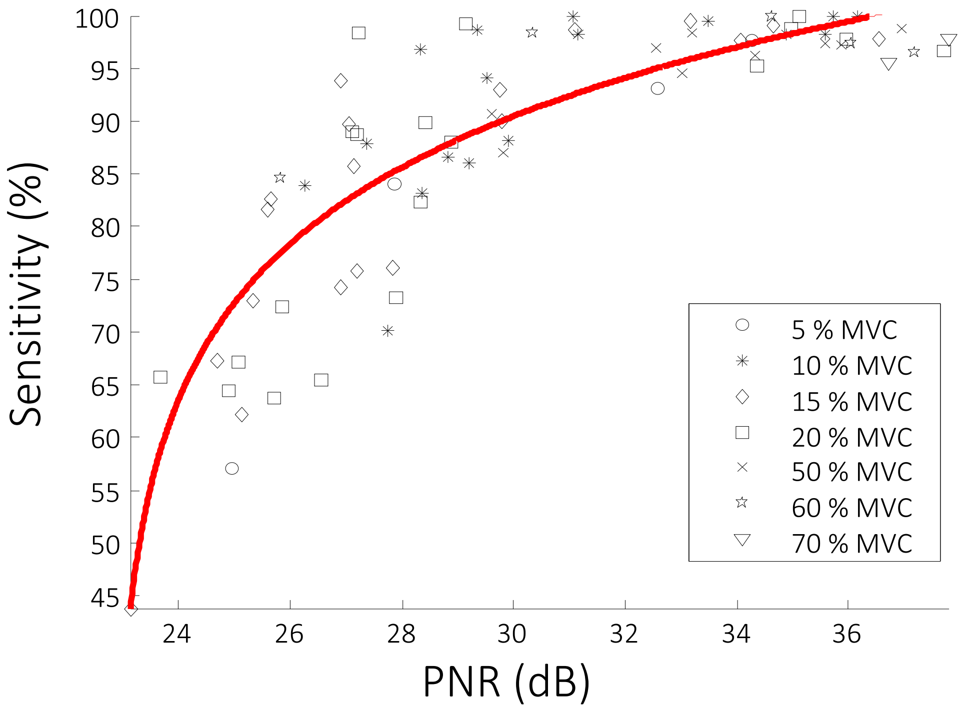
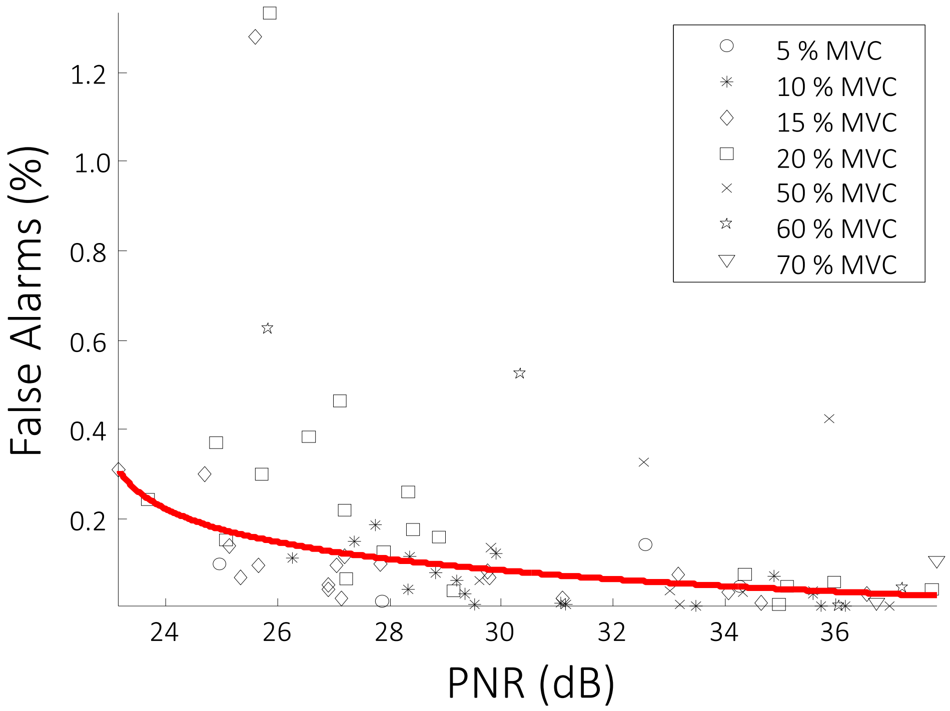
A. Holobar, D. Zazula: *IEEE Trans. on Signal Processing,* 2007, vol. 55, pp. 4487-4496.

Holobar, Minetto & Farina. *Journal of Neural Engineering*, 2014.

C4 – Accuracy assessment: PNR

Simultaneous surface & intramuscular EMG acquistion





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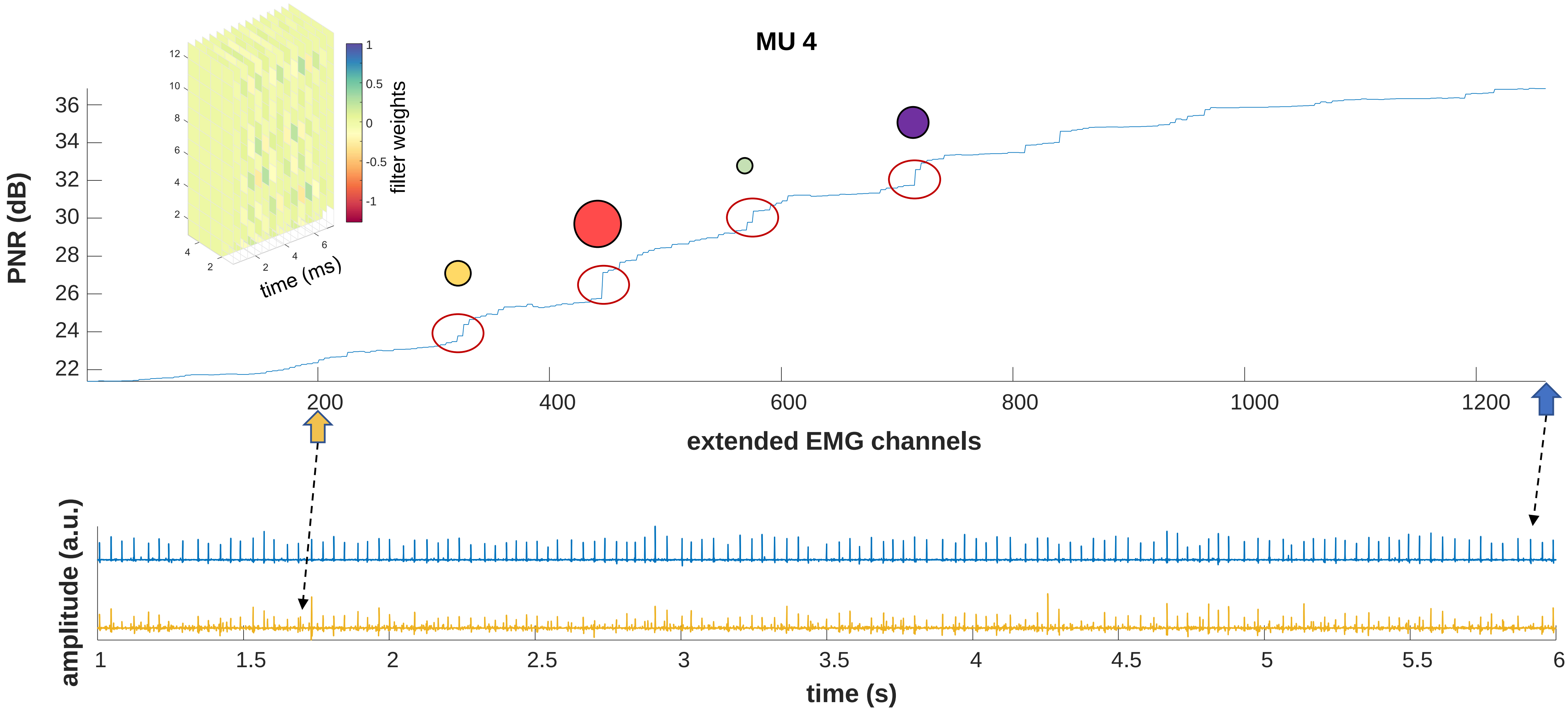
Holobar et al. J. Neural Eng. 2014

C1 - EMG channel selection & extension



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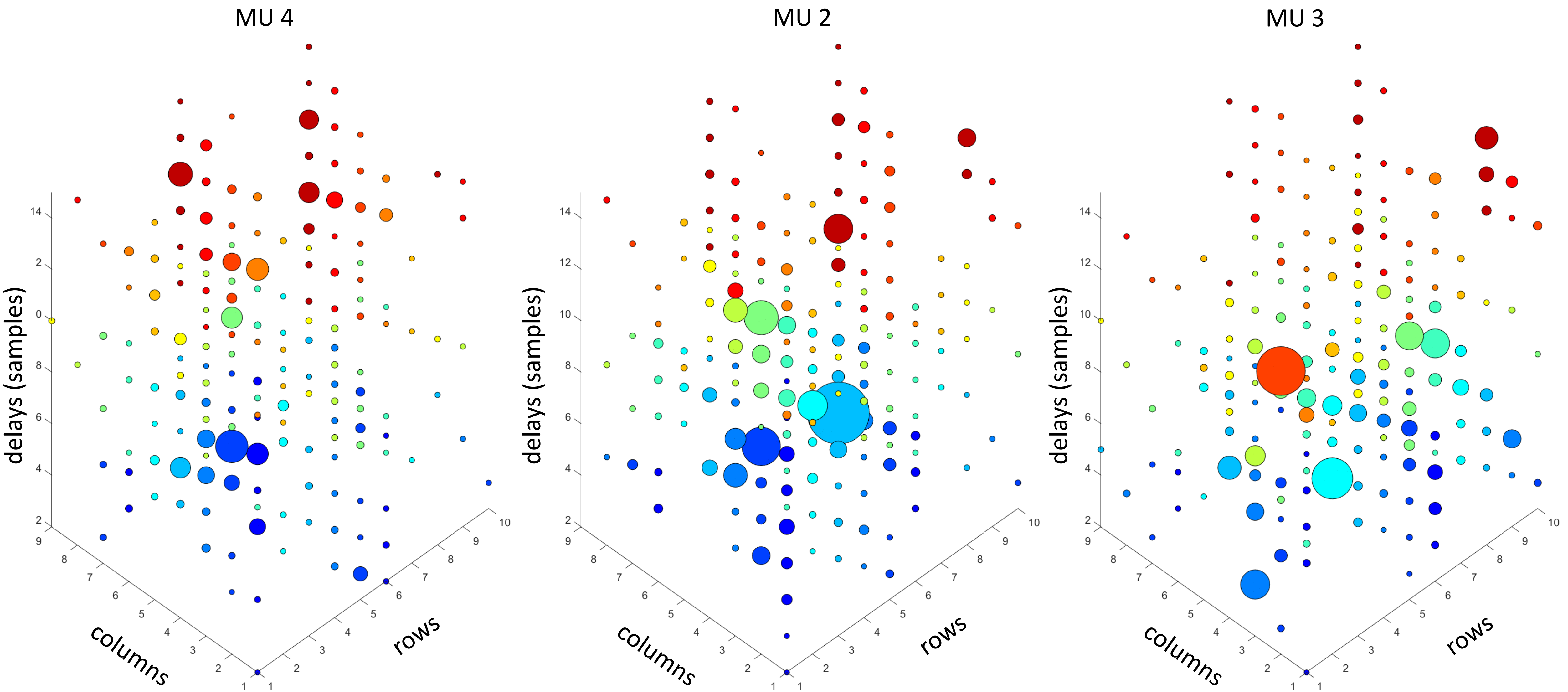
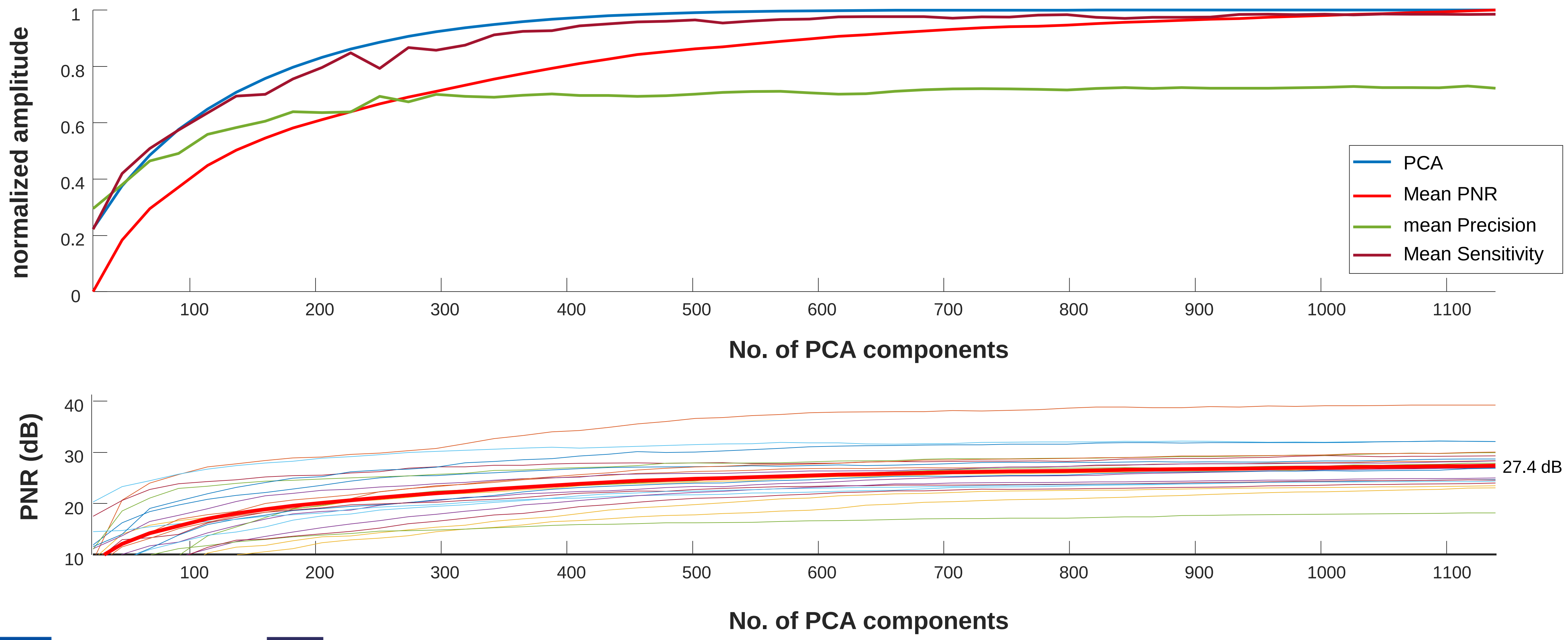
GA No. 10052152

C1 - EMG channel selection & extension



C2 - Dimensionality reduction

Abductor Pollicis Brevis muscle



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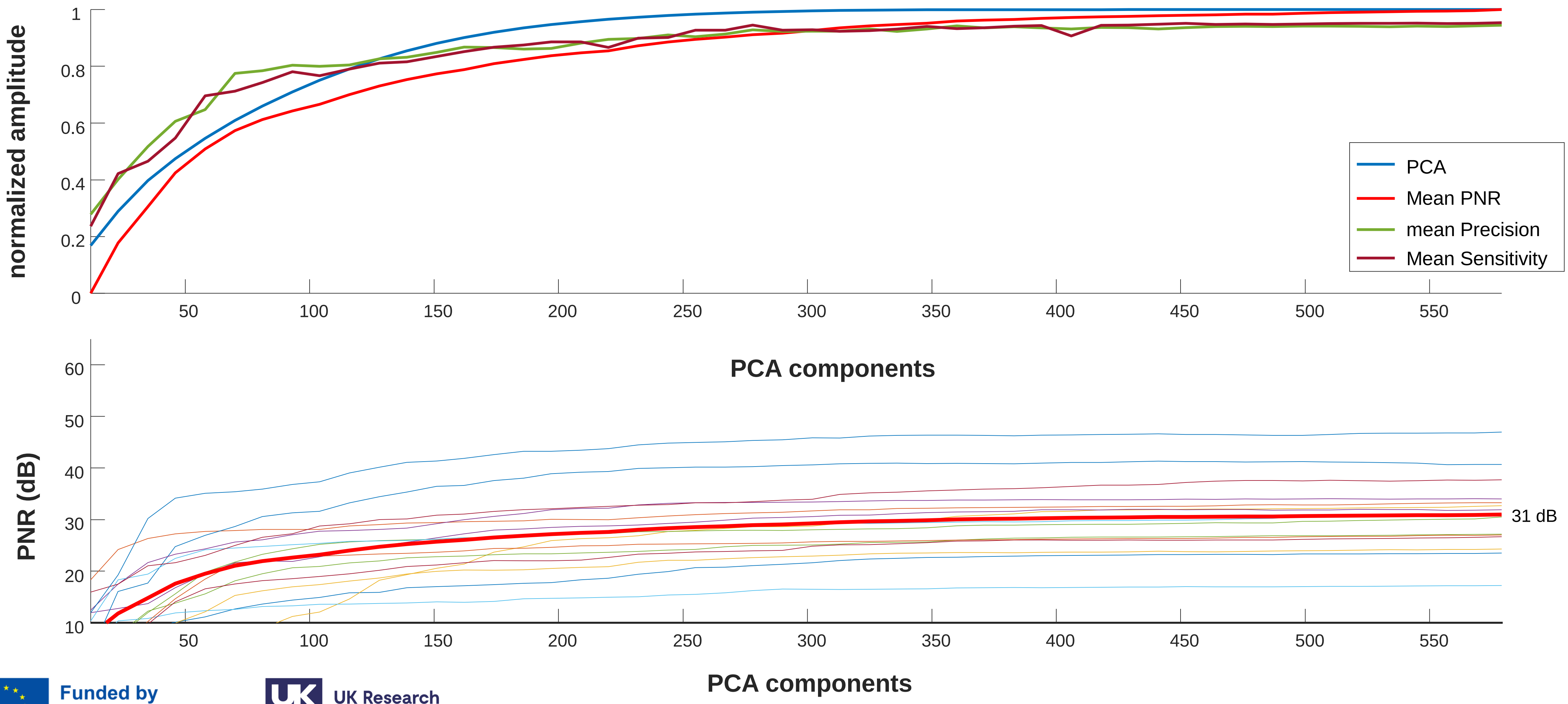
C2 - Dimensionality reduction

First dorsal interosseous muscle



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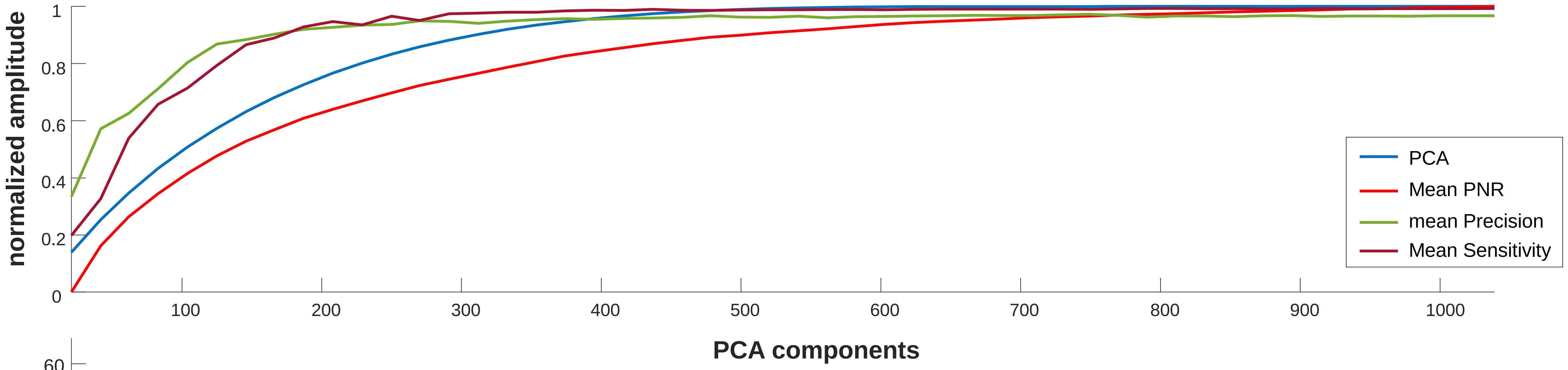
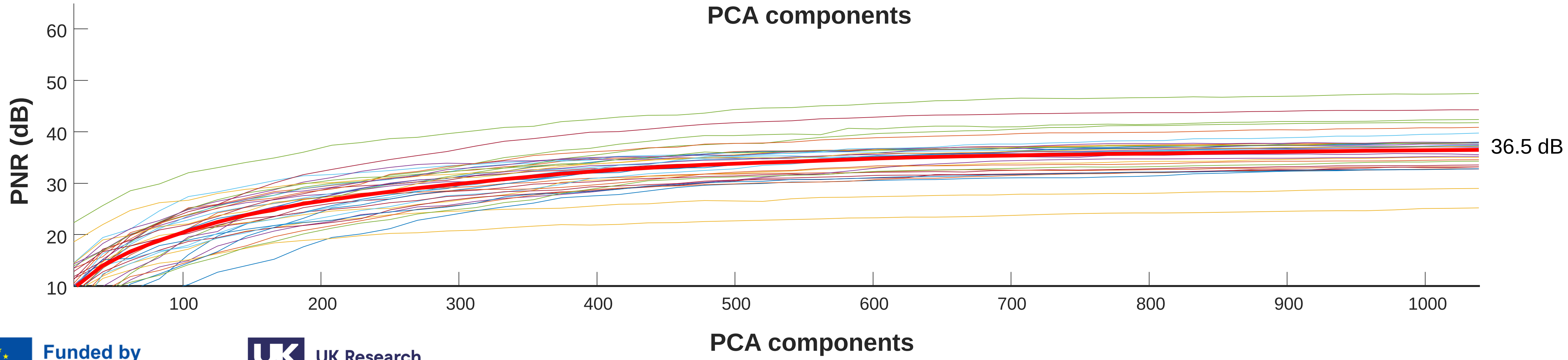
UK Research and Innovation

GA No. 10052152

C2 - Dimensionality reduction

Gastrocnemius Medialis Muscle





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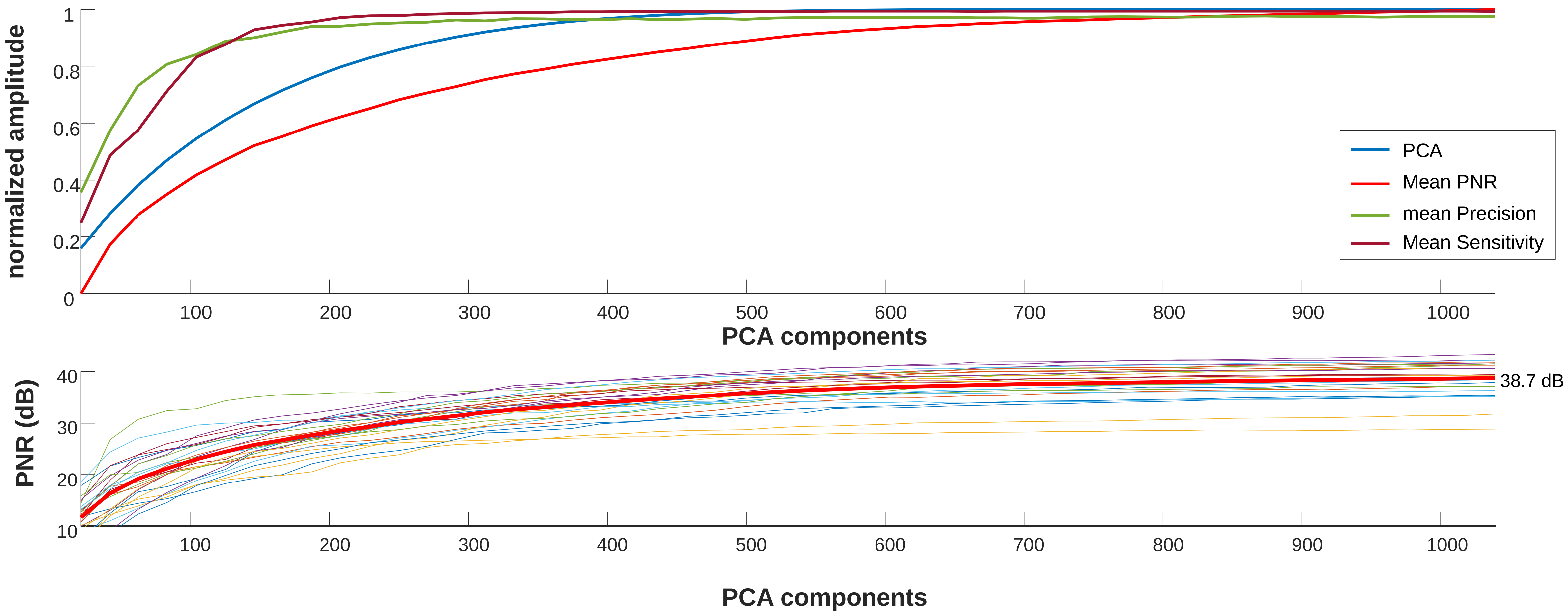
C2 - Dimensionality reduction

Gastrocnemius Lateralis Muscle



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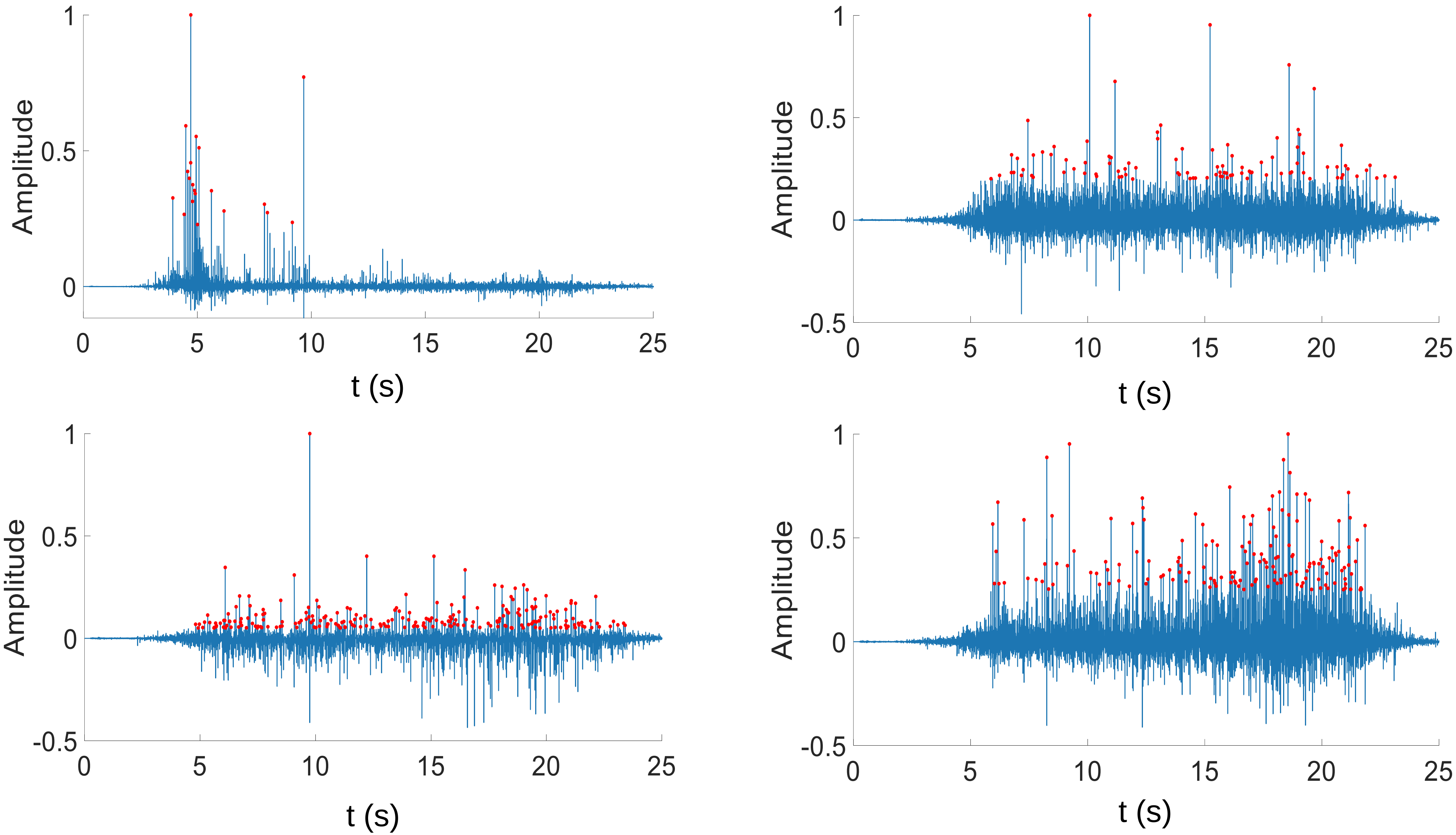
C4 - Bad MU removal



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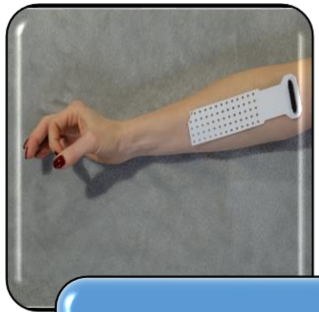
Processing pipeline

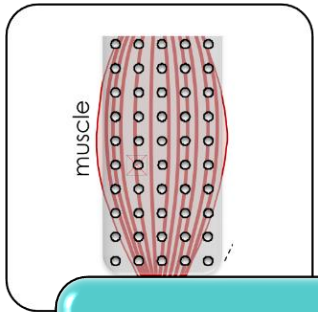
Segment A



HDEMG acquisition

5 steps

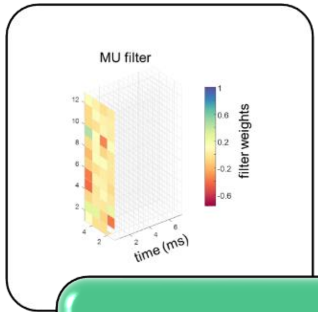
Segment B



HDEMG channel selection

5 steps

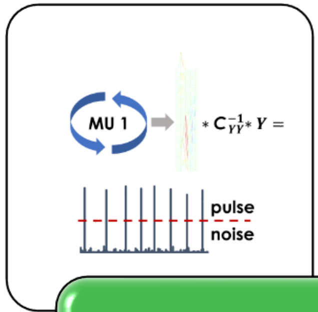
Segment C



BSS-based MU filter estimation

5 steps

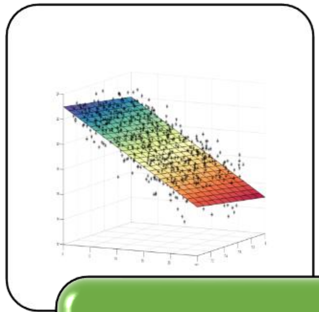
Segment D



MU filter optimization & firings segmentation

5 steps

Segment E



Physiological assessment

5 steps

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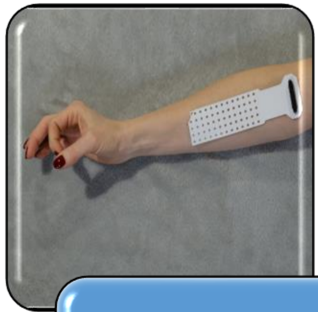
Processing pipeline: Segment D

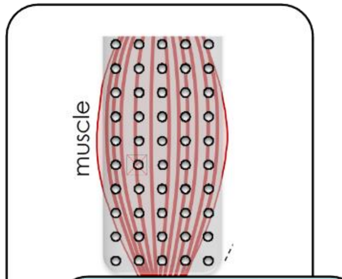
HYBRID NEURO

A



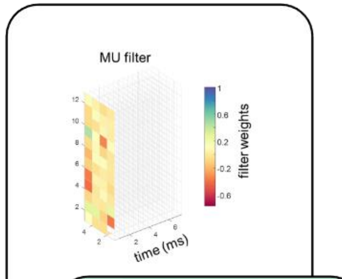
HDEMG acquisition

B



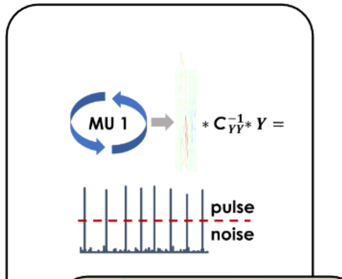
HDEMG channel selection

C



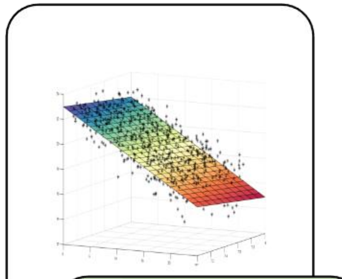
BSS-based MU filter estimation

D



MU filter optimization & firing segmentation

E



Physiological assessment

D1

ROI selection

D2

MU spike outliers removal

D3

Iterative spike-based MU optimization

D4

MU pulse train substraction

D5

Witness-based spike sorting

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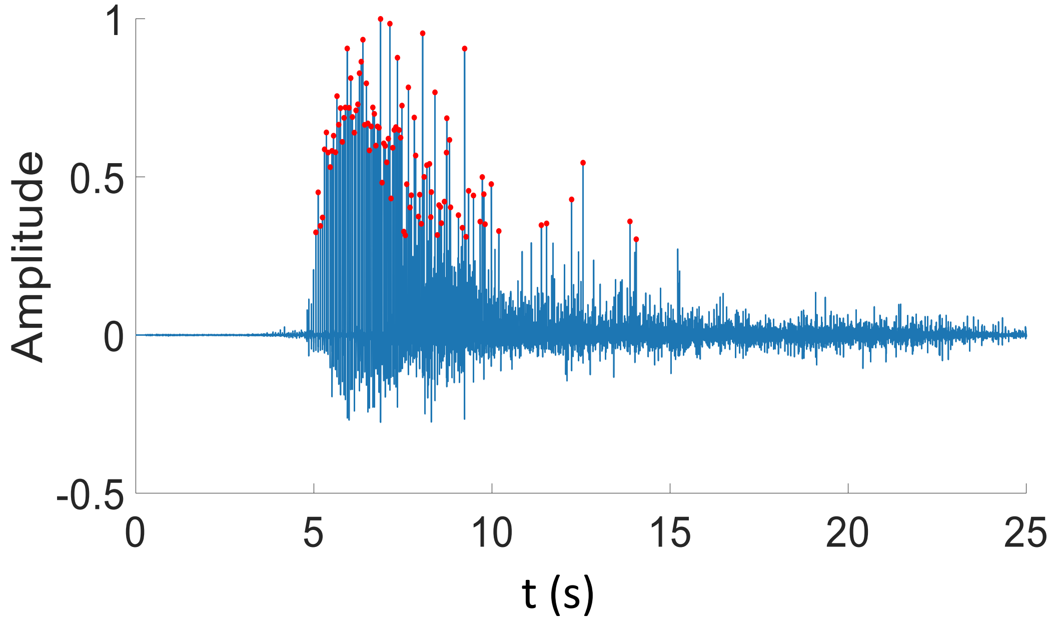
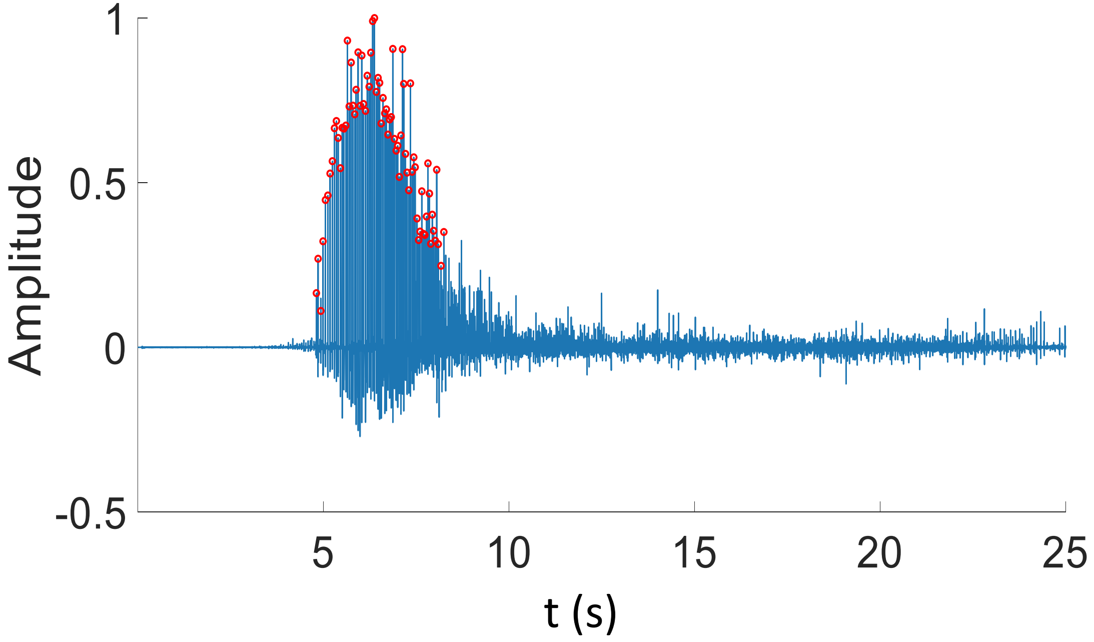
D1- Region of Interest (ROI) selection





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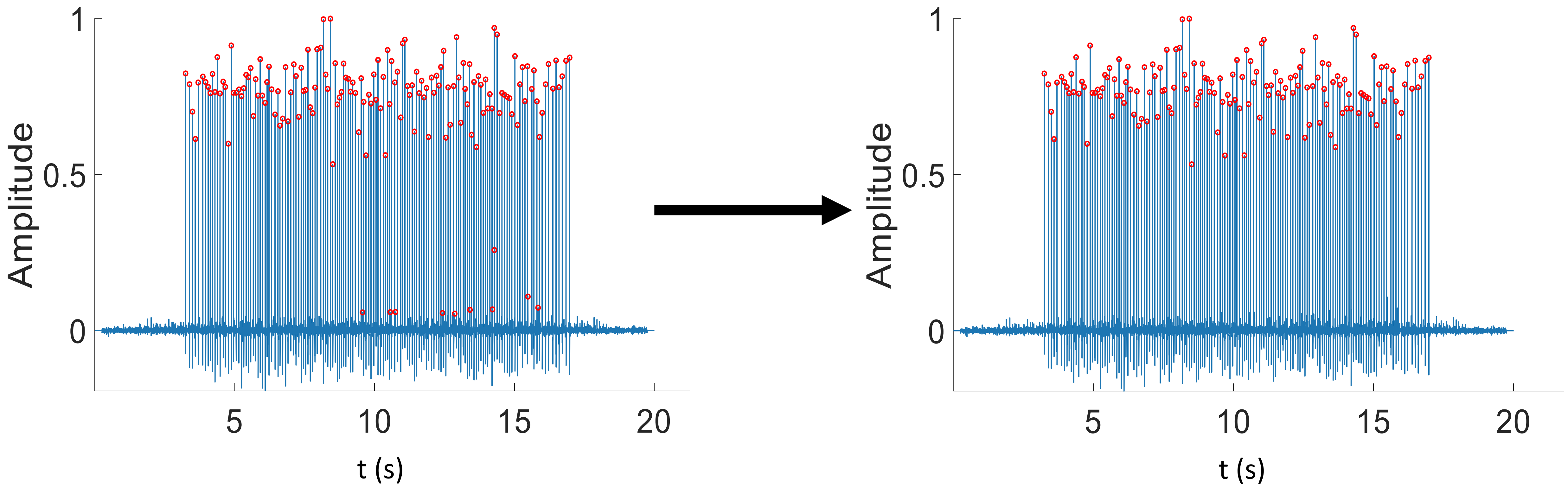
D2- MU spike outliers removal

HYBRID NEURO



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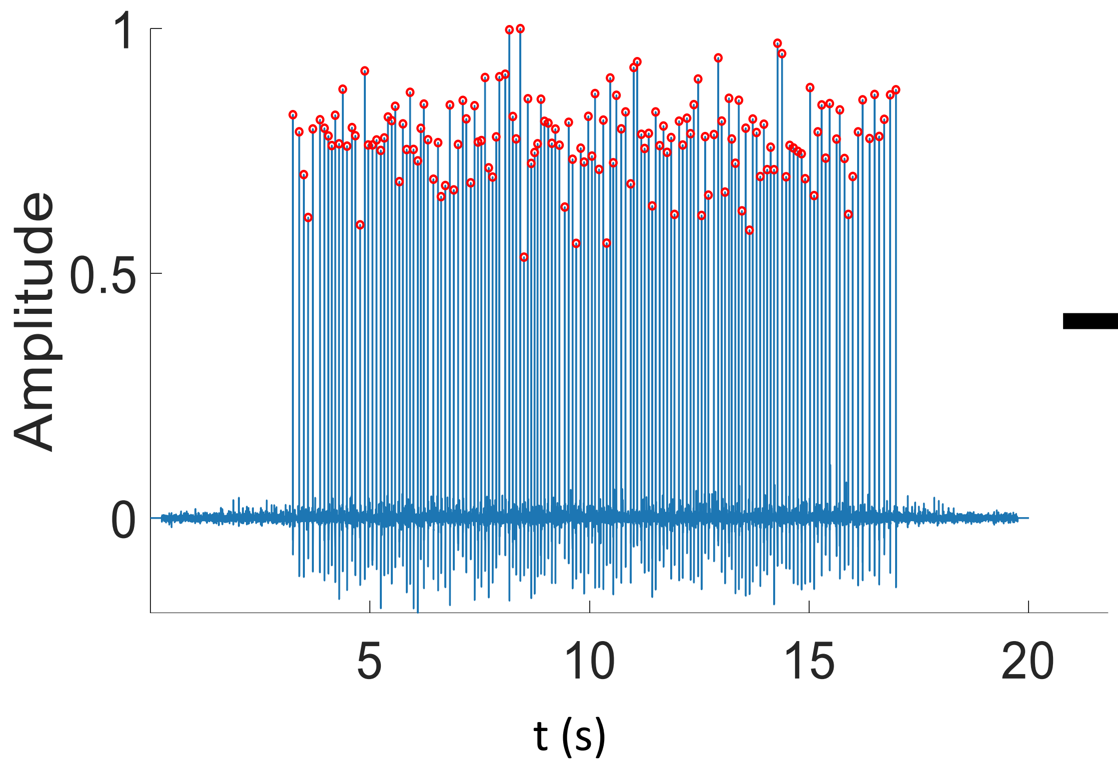
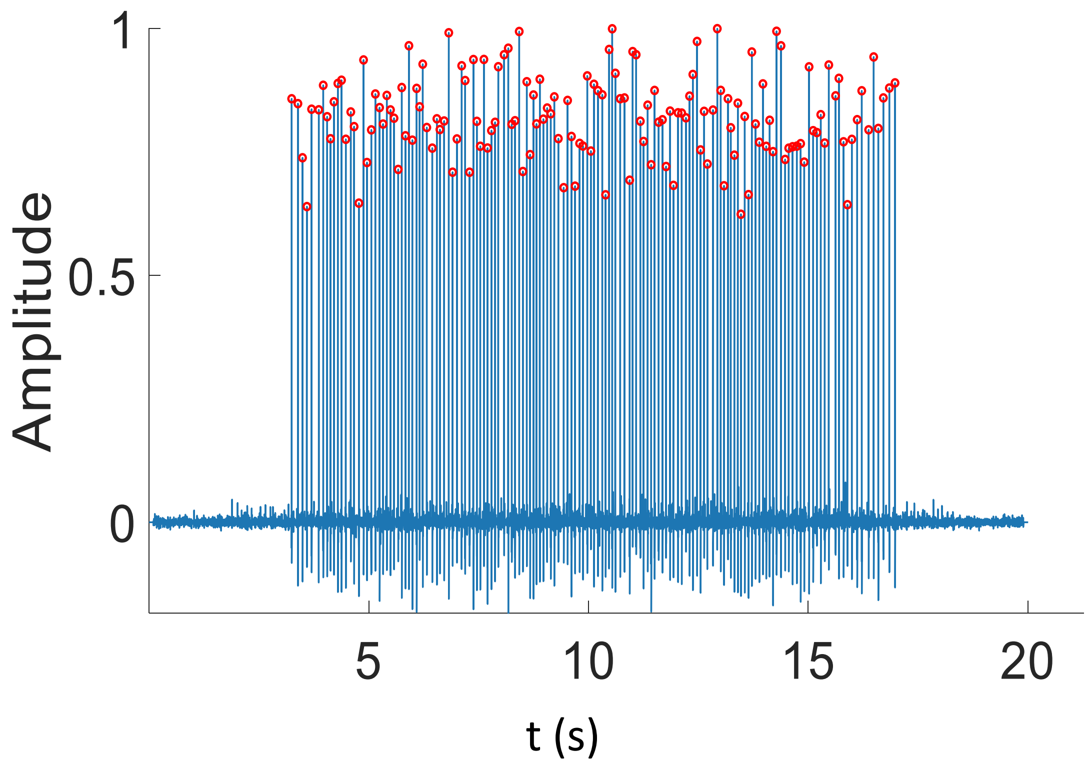
D3- Iterative spike-based MU optimization





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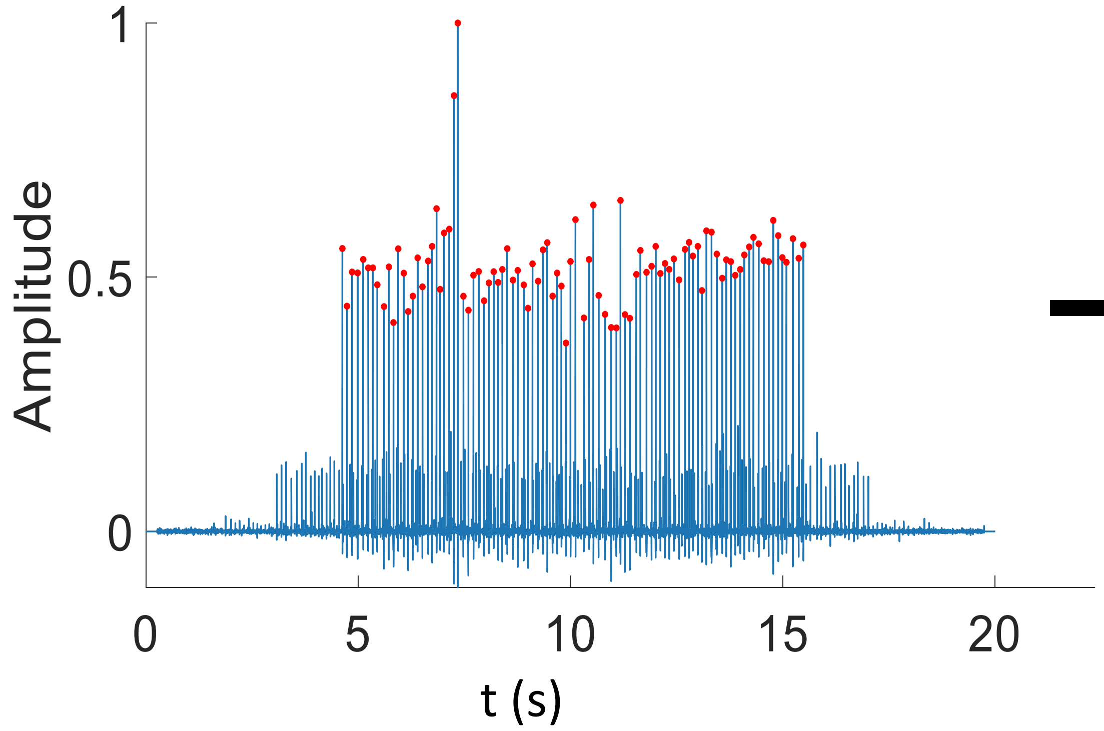
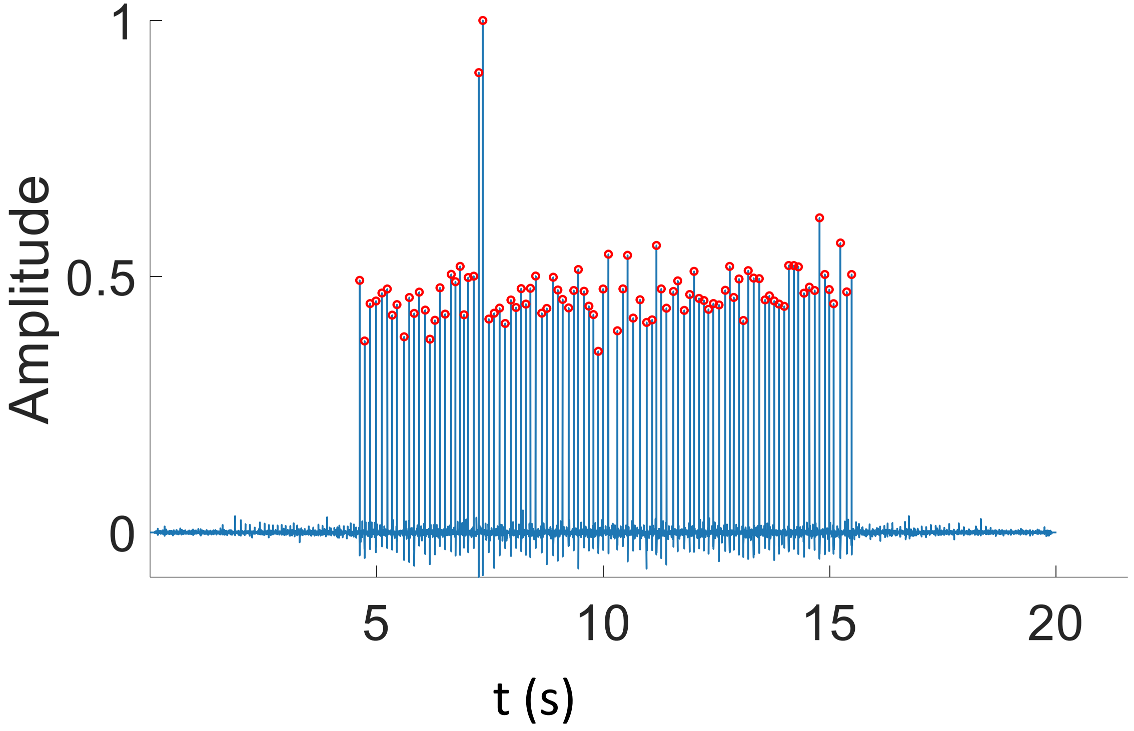
D4- MU pulse train substraction





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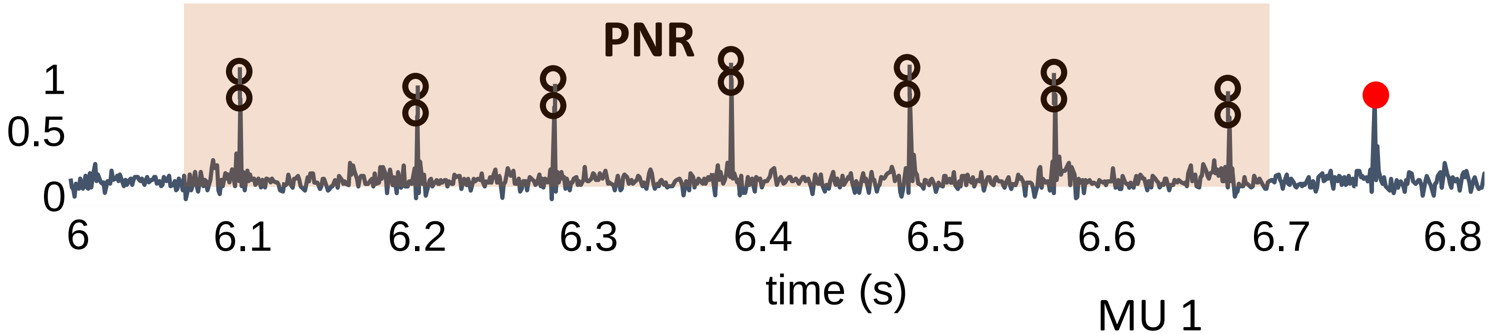
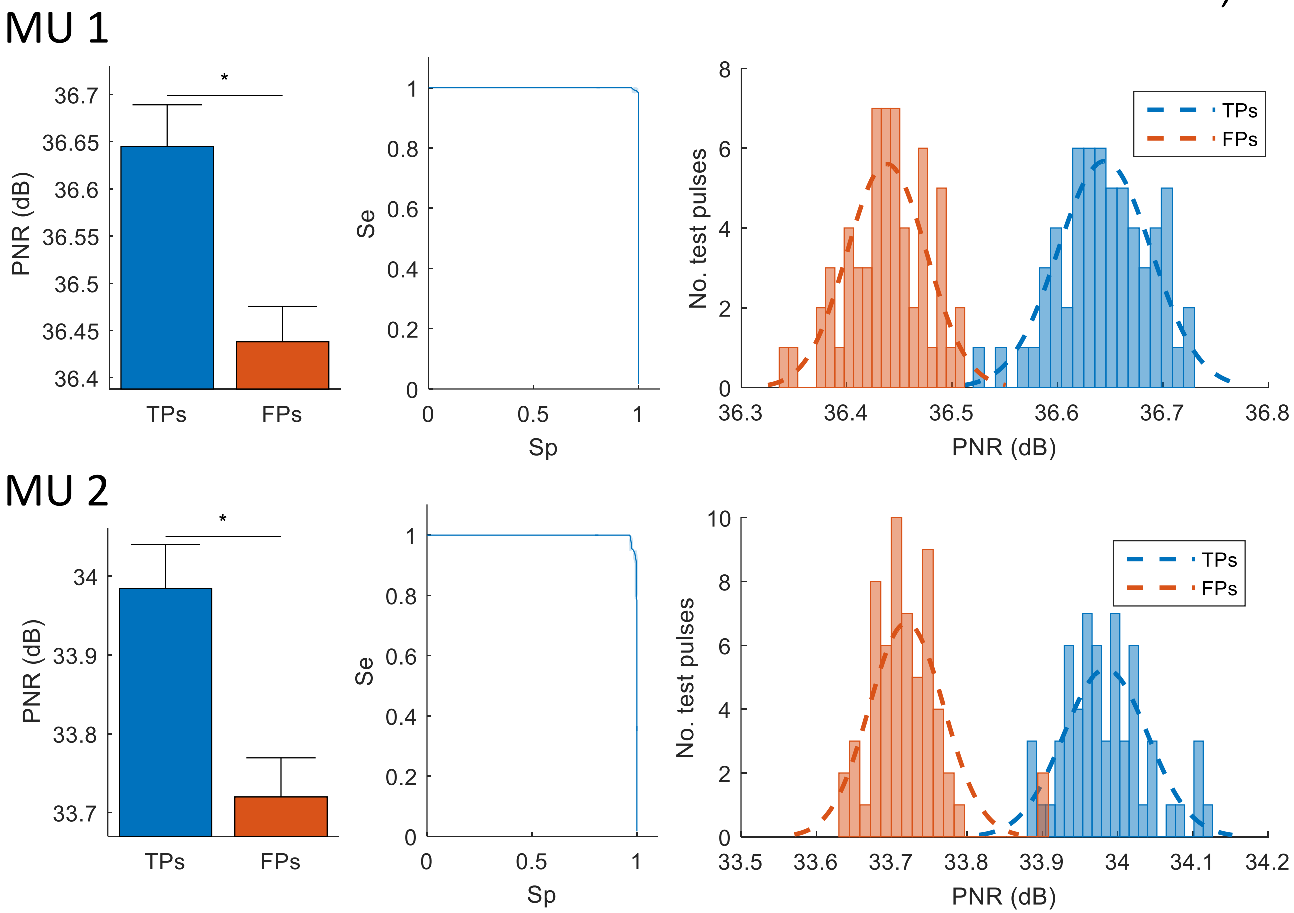
D5 - Witness-based spike sorting



Urh & Holobar, 2019



- Selected MU spikes in identified spike train act as witnesses of decomposition accuracy.
- Witnesses are used to test other spikes.
- Tested spike cannot be its own witness.

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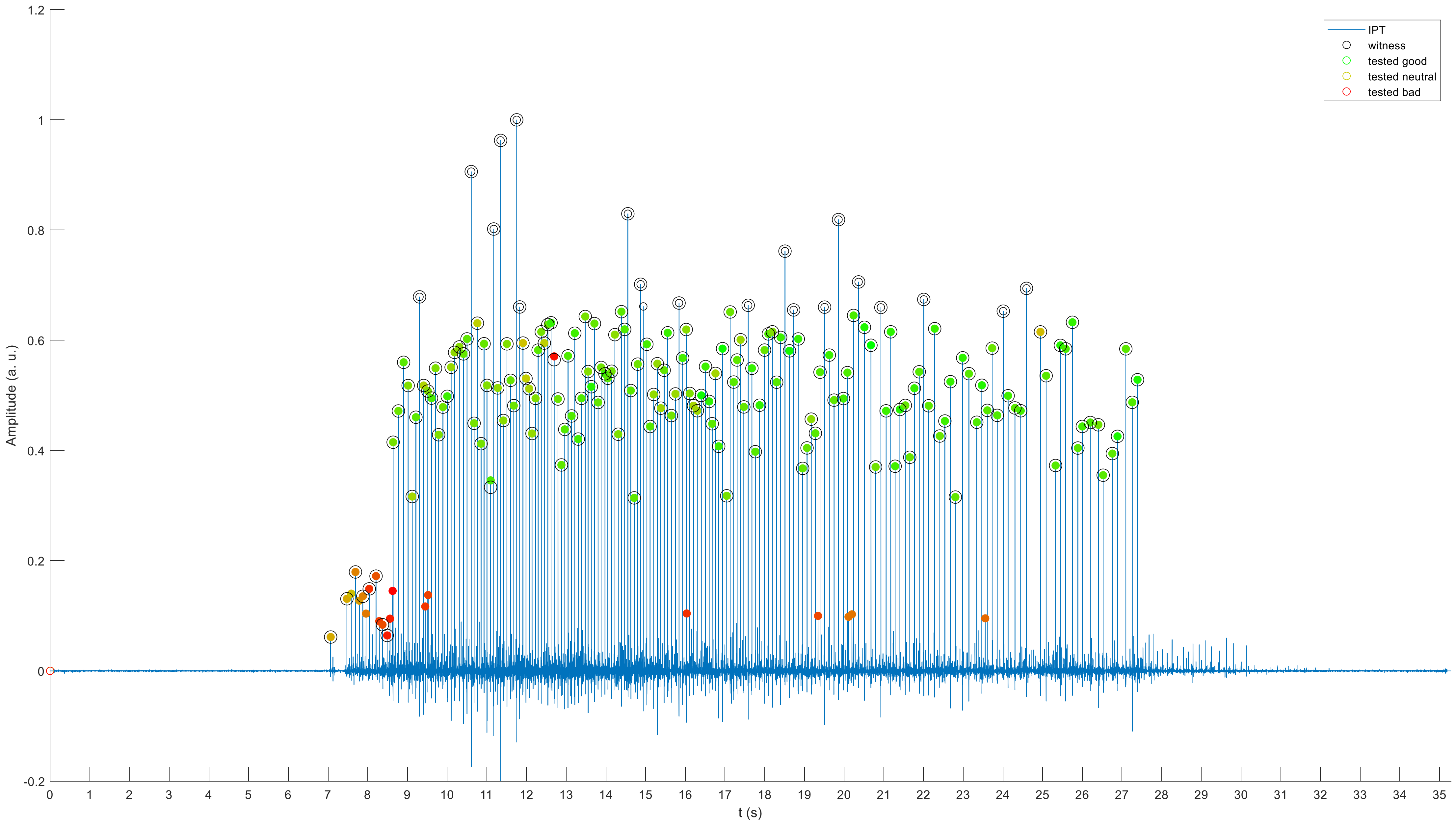
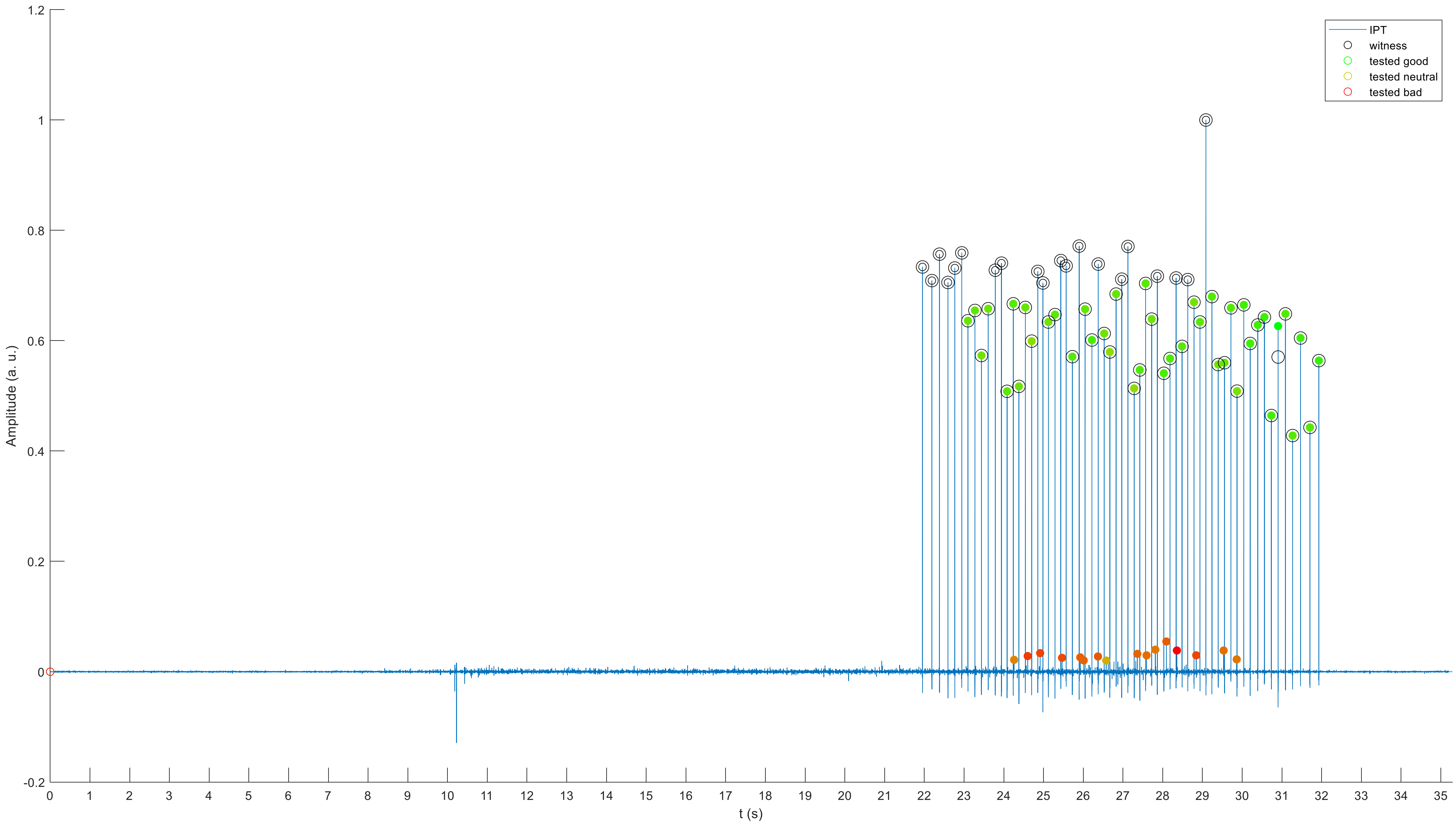
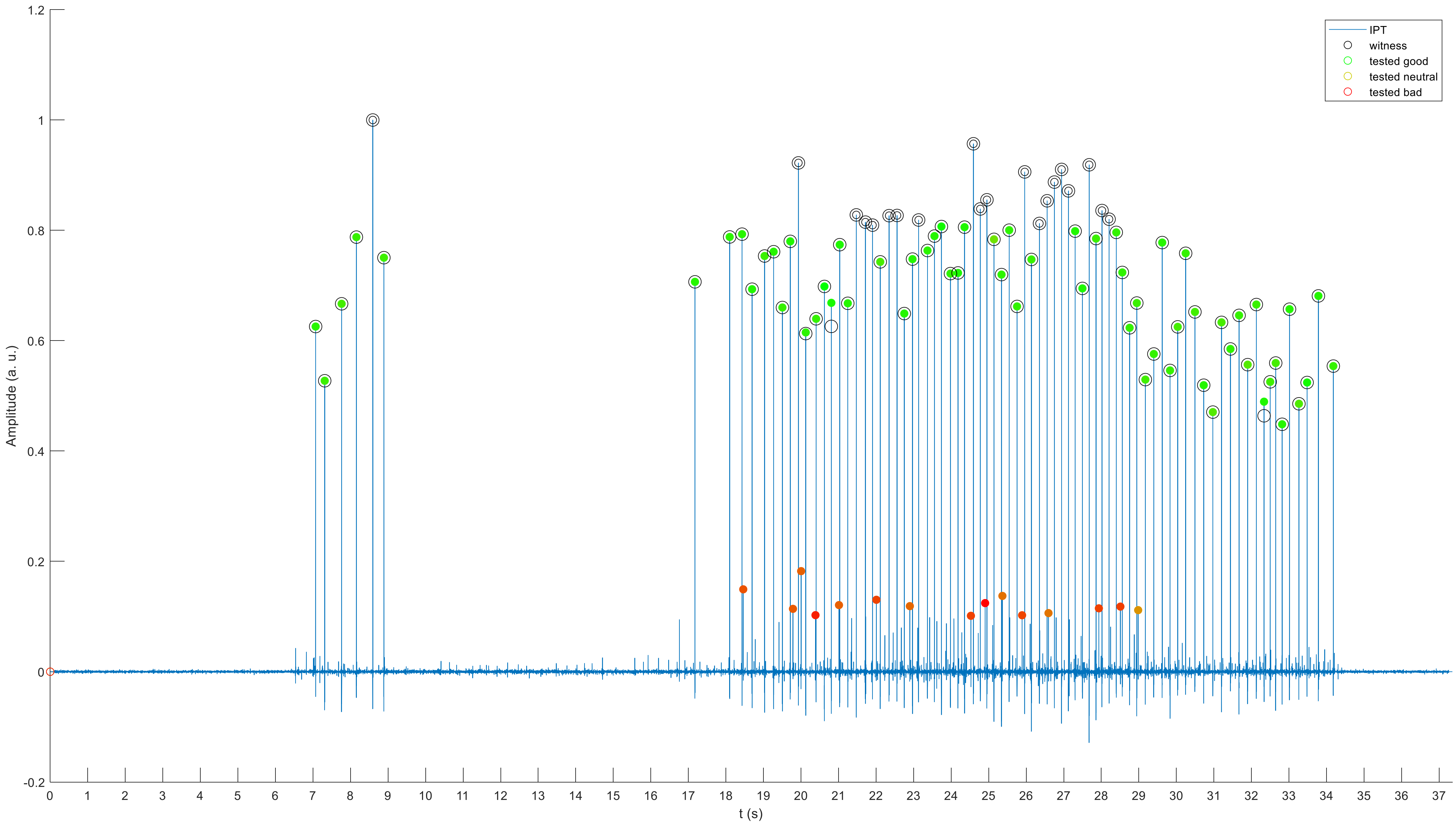


IPT
witness
tested good
tested neutral
tested bad
Amplitude (a. u.)
t (s)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35

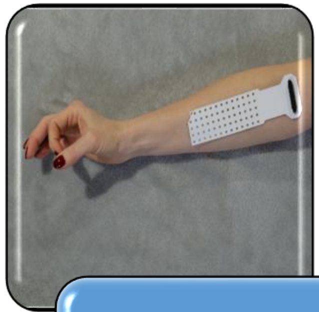
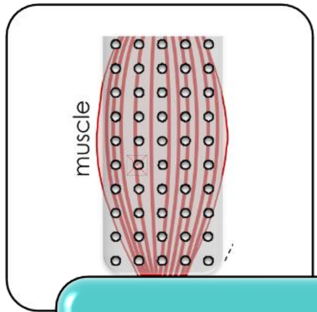
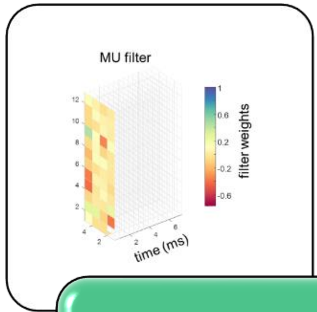
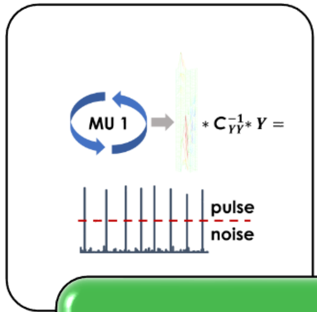
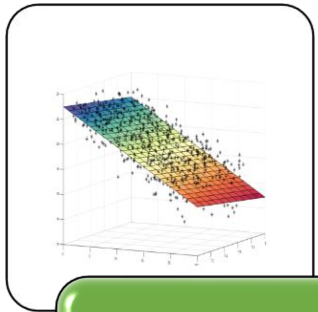

IPT
witness
tested good
tested neutral
tested bad
Amplitude (a. u.)
t (s)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35



IPT
witness
tested good
tested neutral
tested bad
Amplitude (a. u.)
t (s)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37

HYBRID NEURO

Processing pipeline

Segment A	Segment B	Segment C	Segment D	Segment E
				
HDEMG acquisition	**HDEMG channel selection**	**BSS-based MU filter estimation**	**MU filter optimization & firings segmentation**	**Physiological assessment**
5 steps	5 steps	5 steps	5 steps	5 steps

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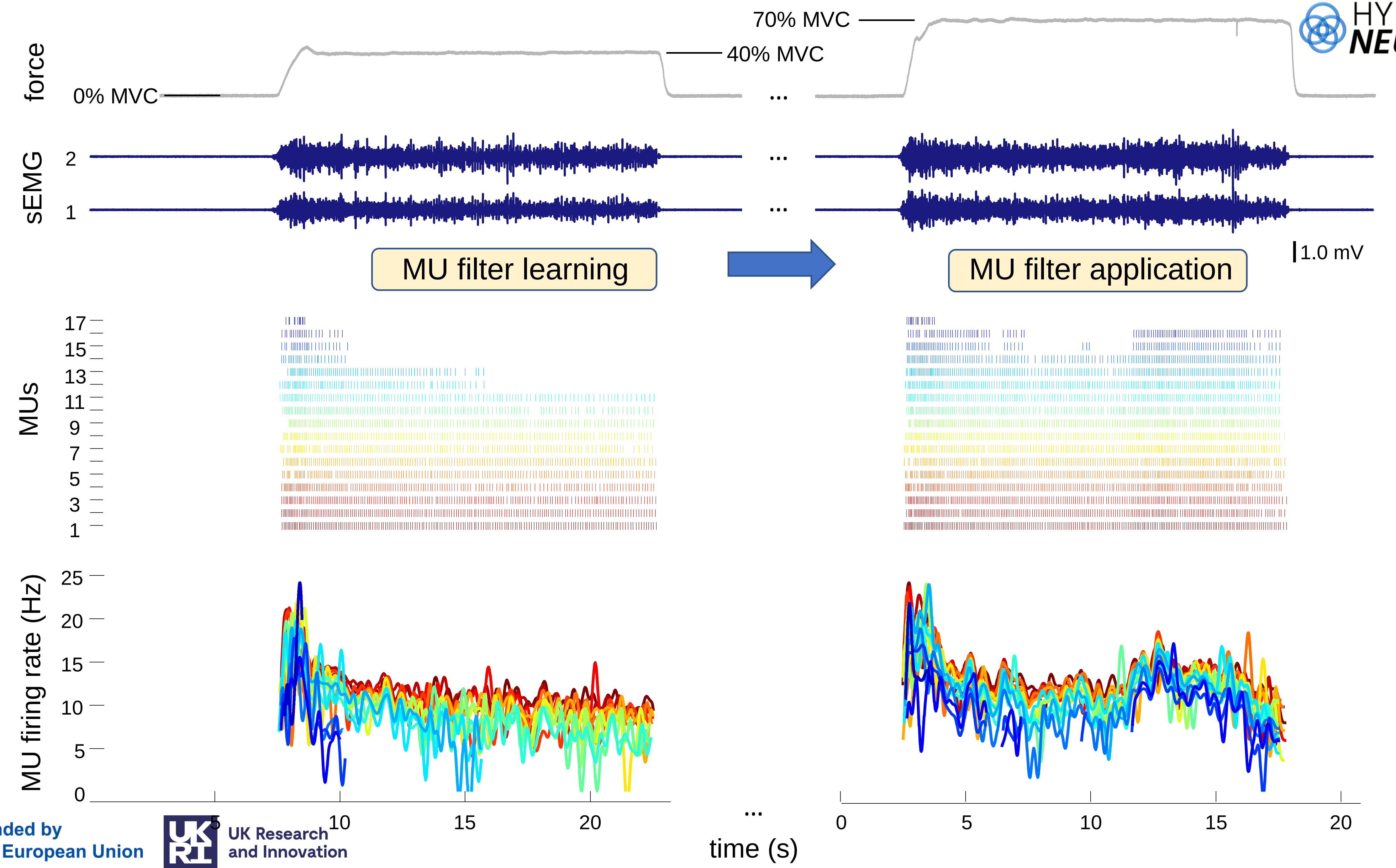

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Holobar & Farina: IEEE Sig. Proc. Magazine, 2021

EXAMPLE 1:
MU tracking across different contraction levels

Frančič & Holobar, IEEE Access 2021

No. of tracked MUs
First Dorsal Interosseous (FDI)

HYBRID NEURO

estimation MVC % \ application MVC %	10	20	30	40	50	70
10	10.4 ± 3 (20, 30, 40, 50, 70)	8.7 ± 2.7 (30, 40, 50, 70)	7.4 ± 2.7 (40, 50, 70)	3.9 ± 4	3.3 ± 3.6	1.7 ± 2.1
20	9.7 ± 2.8 (20, 50, 70)	13.6 ± 2.1 (40, 50, 70)	12 ± 2.1 (40, 50, 70)	9.4 ± 2.8 (50, 70)	5.9 ± 3.6 (70)	2 ± 2.8
30	7.9 ± 3.7 (20, 30, 40)	12.9 ± 3.3 (30)	16.7 ± 2.9 (40, 50, 70)	14.7 ± 3.5 (50, 70)	10.4 ± 4.9 (70)	5.1 ± 4.8
40	4.7 ± 3.9 (20, 30, 40, 50)	9.3 ± 3.5 (40, 50)	13.1 ± 4.5 (40)	15.9 ± 4.5 (70)	14.6 ± 4.2 (70)	8.6 ± 5.4
50	3.6 ± 4.3 (20, 30, 40, 50, 70)	7.1 ± 4.9 (40, 50, 70)	10 ± 4.4 (50, 70)	12 ± 4.5 (50)	15.9 ± 3.1 (70)	12.3 ± 3.7
70	1.9 ± 3.6 (30, 40, 50, 70)	2.7 ± 4.4 (30, 40, 50, 70)	4.3 ± 4.3 (50, 70)	6.1 ± 5.8 (50, 70)	9.7 ± 5.6 (70)	15.6 ± 5.6

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EXAMPLE 2:

MU tracking across different contraction levels

Frančič & Holobar, IEEE Access 2021

No. of tracked MUs

Tibialis Anterior (TA)

estimation MVC % \ application MVC %	10	20	30	50	60	70
10	11.7 ± 5.2 *(20, 30, 50, 60, 70)*	6 ± 4.8 *(30, 50, 60, 70)*	3.1 ± 4.5 *(70)*	0.3 ± 0.5	0.1 ± 0.3	0.2 ± 0.4
20	6.4 ± 4.5 *(20, 50, 60, 70)*	13.8 ± 5.4 *(30, 50, 60, 70)*	7.6 ± 6.3 *(50, 60, 70)*	1.8 ± 2.8 *(60, 70)*	0.2 ± 0.4	0.1 ± 0.3
30	4.8 ± 4.6 *(20, 30, 70)*	9.4 ± 5.4 *(30, 50, 60, 70)*	14.1 ± 6 *(50, 60, 70)*	3.7 ± 3.4 *(60, 70)*	1.1 ± 1.5	0.2 ± 0.7
50	2 ± 3 *(30, 50, 60)*	4.3 ± 5.7 *(30, 50, 60)*	8.8 ± 5.9 *(50, 70)*	17.2 ± 6.4 *(60, 70)*	8.9 ± 5.9 *(70)*	1.2 ± 1.3
60	1 ± 1.7 *(30, 50, 60, 70)*	2.1 ± 2.2 *(30, 50, 60)*	5.7 ± 3.1 *(50, 60)*	14 ± 5.3 *(60, 70)*	16.9 ± 6.7 *(70)*	5.3 ± 4.6
70	0.2 ± 0.7 *(20, 30, 50, 60, 70)*	0.2 ± 0.7 *(30, 50, 60, 70)*	1.6 ± 1.7 *(50, 60, 70)*	7.1 ± 4 *(60, 70)*	11 ± 5.3 *(70)*	13.8 ± 4.7

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EXAMPLE 4:

MU tracking across different contraction levels

Frančič & Holobar, IEEE Access 2021

HYBRID NEURO

No. of tracked MUs

Biceps Brachi (BB)

application MVC %

estimation MVC %	10	20	30	50	60	70
10	5.8 ± 2.9 *(20, 30, 50, 60)*	0.5 ± 0.8 *(50)*	0.7 ± 1.2 *(50)*	0.5 ± 0.5	0.3 ± 0.5	0.7 ± 1.6
20	2 ± 2.4	4.7 ± 3 *(30, 50, 60, 70)*	2.2 ± 2.6	1.3 ± 2 *(60)*	1 ± 1.3	0.5 ± 0.8
30	0.8 ± 2 *(30, 50, 70)*	2.5 ± 4 *(30, 60)*	6 ± 3 *(50, 60, 70)*	2.3 ± 2.1	0.8 ± 0.8	0.5 ± 0.8
50	0.5 ± 1.2 *(30, 50, 60, 70)*	1 ± 2 *(50, 70)*	2.8 ± 3.2	6.8 ± 2.9 *(60, 70)*	1.7 ± 2	0.3 ± 0.8
60	0.5 ± 1.2 *(50, 60, 70)*	0.2 ± 0.4 *(50, 60, 70)*	1.7 ± 2.4	4.2 ± 4.3 *(60, 70)*	5.8 ± 4 *(70)*	0.2 ± 0.4
70	0 ± 0 *(20, 50, 70)*	0 ± 0 *(50, 70)*	0.8 ± 1.2	1.7 ± 1.2	0.7 ± 1.2 *(70)*	4.8 ± 4.1

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Segment E - Physiological assessment: Isometric voluntary contractions

Physiological Assessment & Applications

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Voluntary contractions: identified MUs

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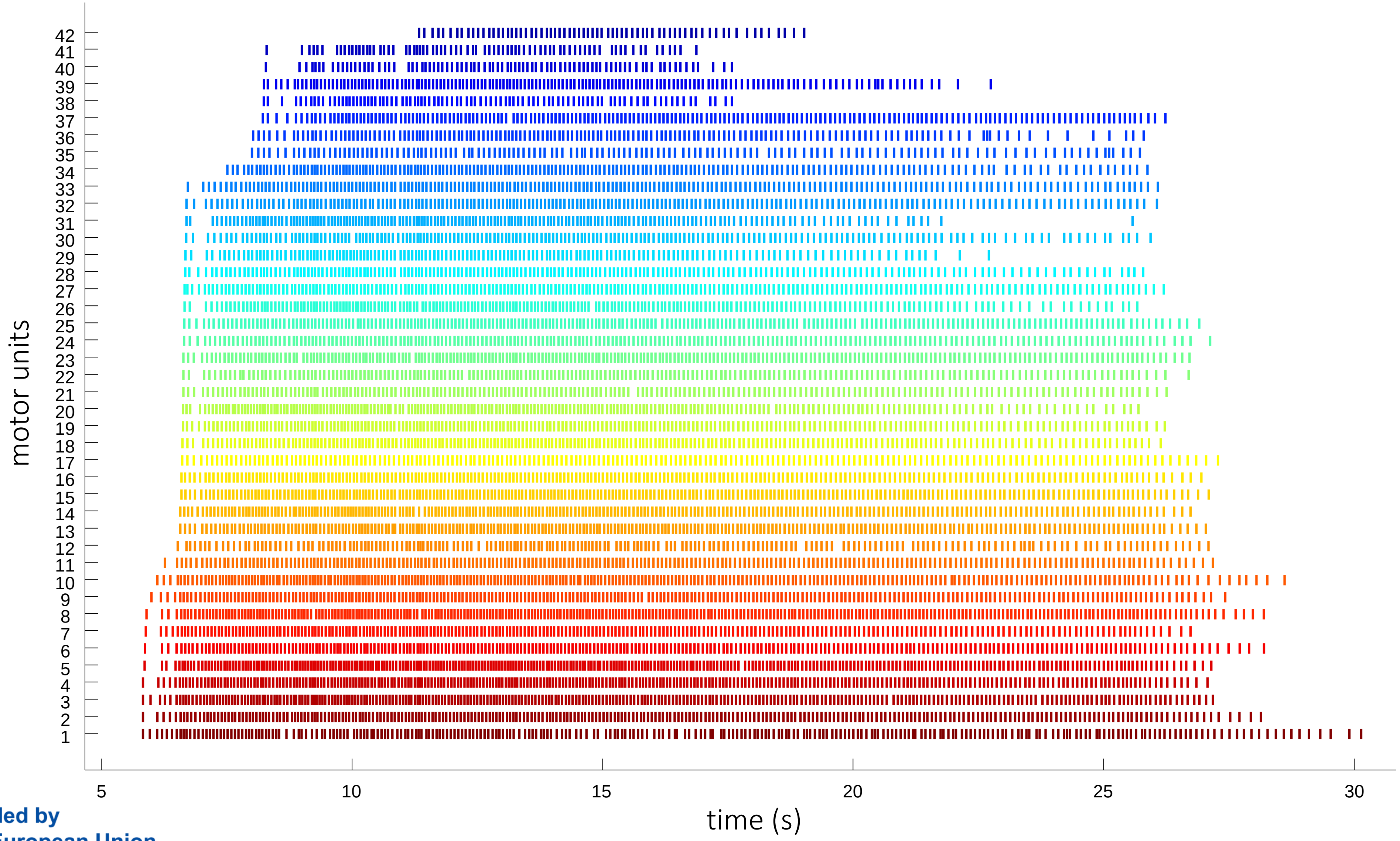
Gastrocnemius medialis, 30% MVC



Divjak et al. *Frontiers in physiology* 12 (2022)

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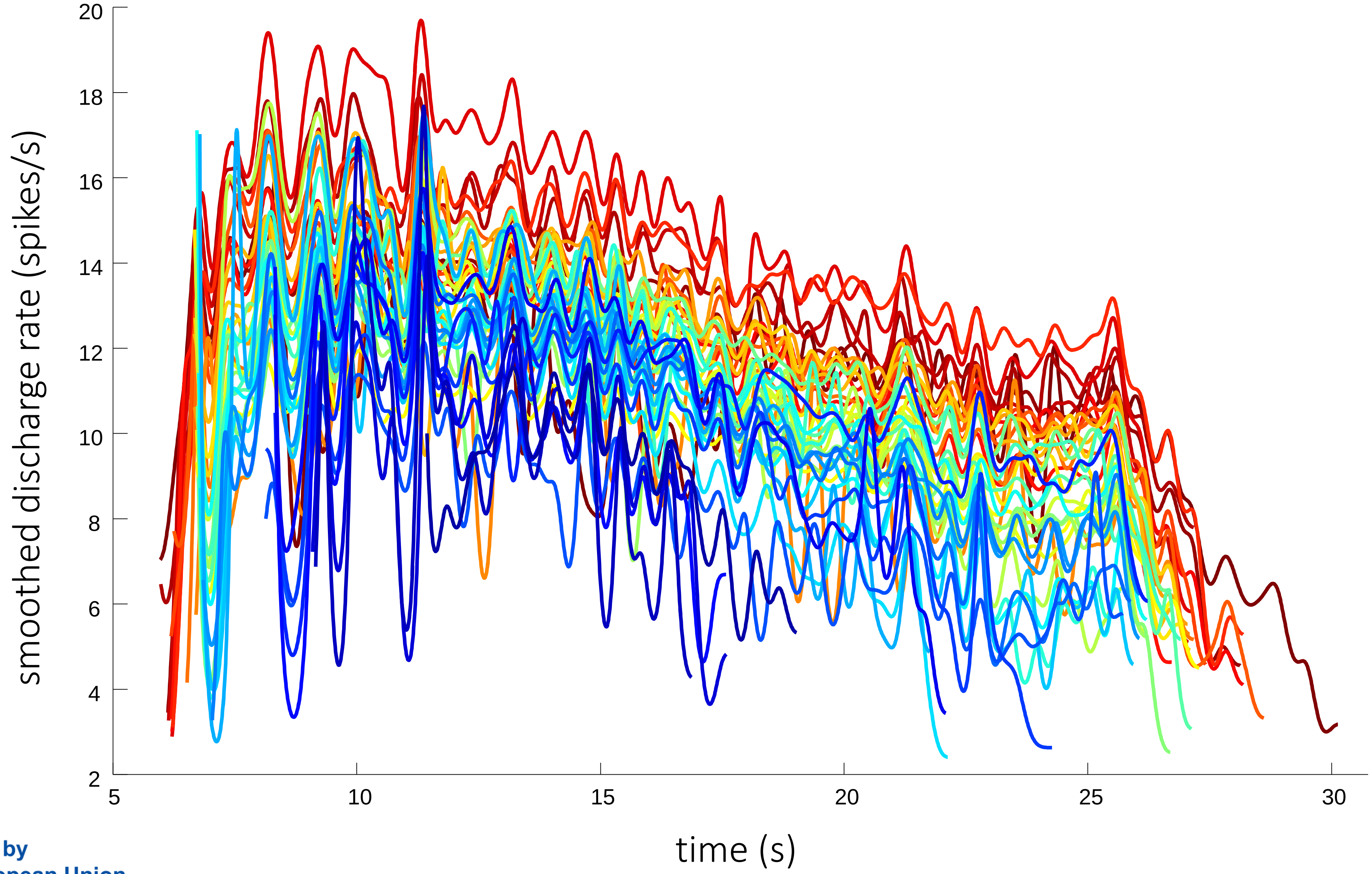
Smoothed MU discharge rates

Gastrocnemius medialis, 30% MVC



Divjak et al. *Frontiers in physiology* 12 (2022)

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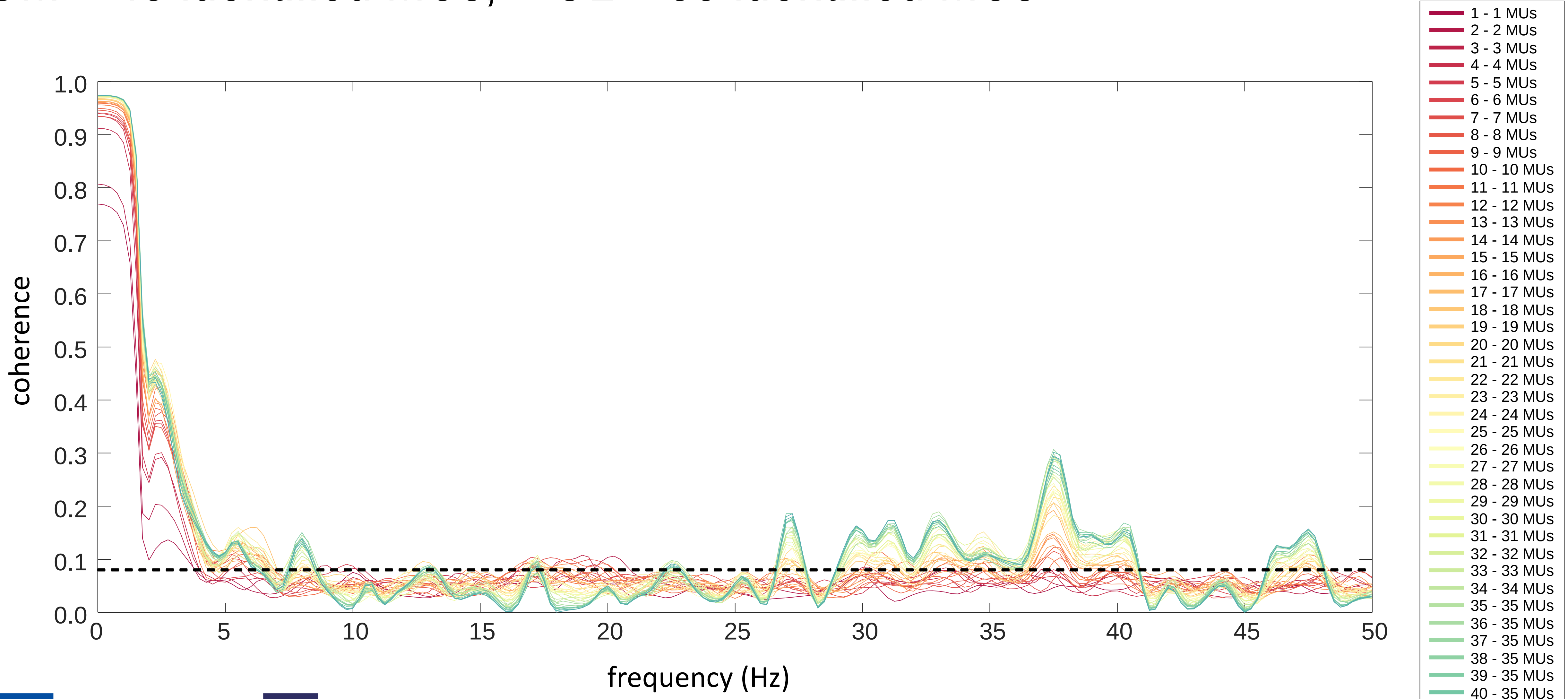
Experimental HDEMG: CST

GM – 43 identified MUs, GL – 35 identified MUs



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Activity index (AI)

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hdEMG model: $\mathbf{y}(n) = \overline{\mathbf{H}}\bar{\mathbf{t}}(n) + \boldsymbol{\omega}(n)$

MU spike trains: $t_j(\mathrm{n}) = \sum_k \delta\left(n - \tau_j(k)\right)$, *j=1…N*

MUAPs: $\overline{\mathbf{H}} = [\overline{\mathbf{H}_1} \ldots \overline{\mathbf{H}_N}]$ $\qquad \overline{\mathbf{H}}_j = \begin{bmatrix} \overline{h_{1j}}(0) & \ldots & \overline{h_{1j}}(L) \\ \vdots & \ddots & \vdots \\ \overline{h_{Mj}}(0) & \ldots & \overline{h_{Mj}}(L) \end{bmatrix}$

CKC: $\hat{t}_j(n) = \mathbf{c}_{\mathrm{t_j y}}^{\mathrm{T}} \mathbf{C}_{\mathbf{y}}^{-1} \mathbf{y}(n) \approx \mathbf{c}_{\mathrm{t_j t}}^{\mathrm{T}} \mathbf{C}_{\mathbf{t}}^{-1} \mathbf{t}(n)$

MU filter $\mathbf{c}_{\mathrm{t_j y}}^{\mathrm{T}} \mathbf{C}_{\mathbf{y}}^{-1}$ needs to be estimated for every motor unit

CST – sum of individual MU spike trains (Negro & Farina, J. of Physiology 2011)

Activity Index: $AI(n) = \boldsymbol{y}(n)^T \mathbf{C}_{\boldsymbol{y}}{}^{-1} \boldsymbol{y}(n) \approx \bar{\mathbf{t}}(n)^T \mathbf{C}_{\bar{\mathbf{t}}}{}^{-1} \bar{\mathbf{t}}(n)$

superimposed spike trains from all MUs in the detection volume

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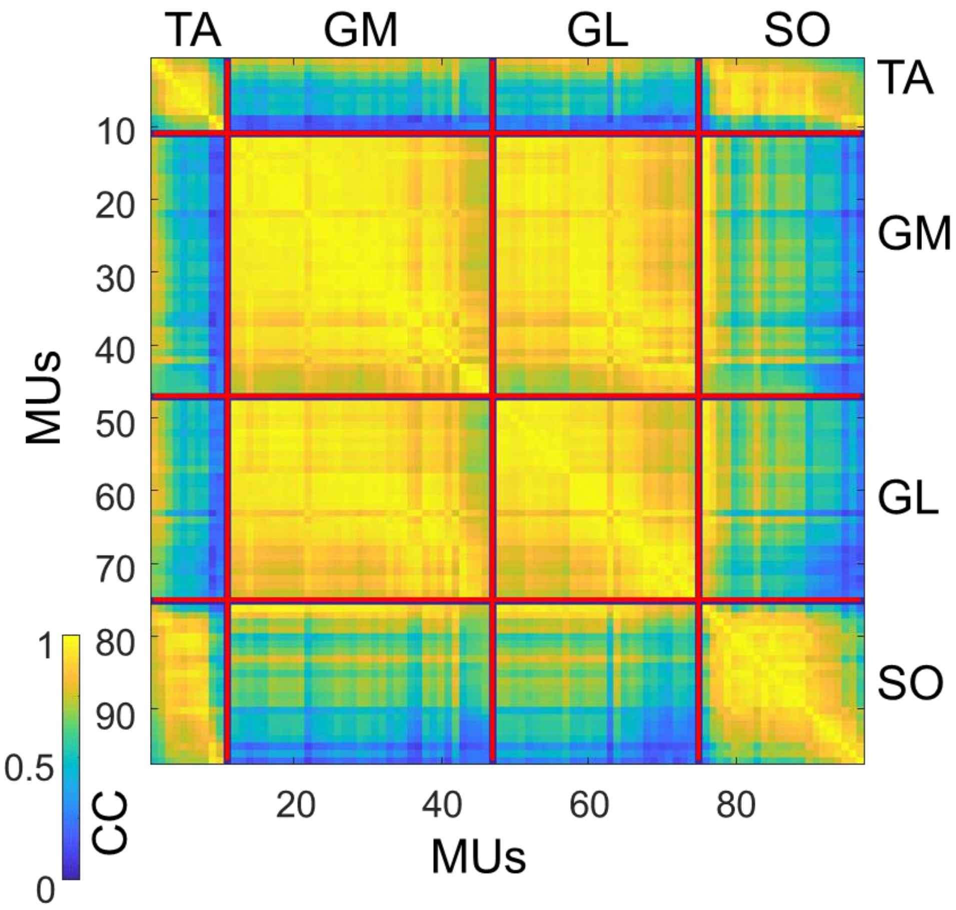
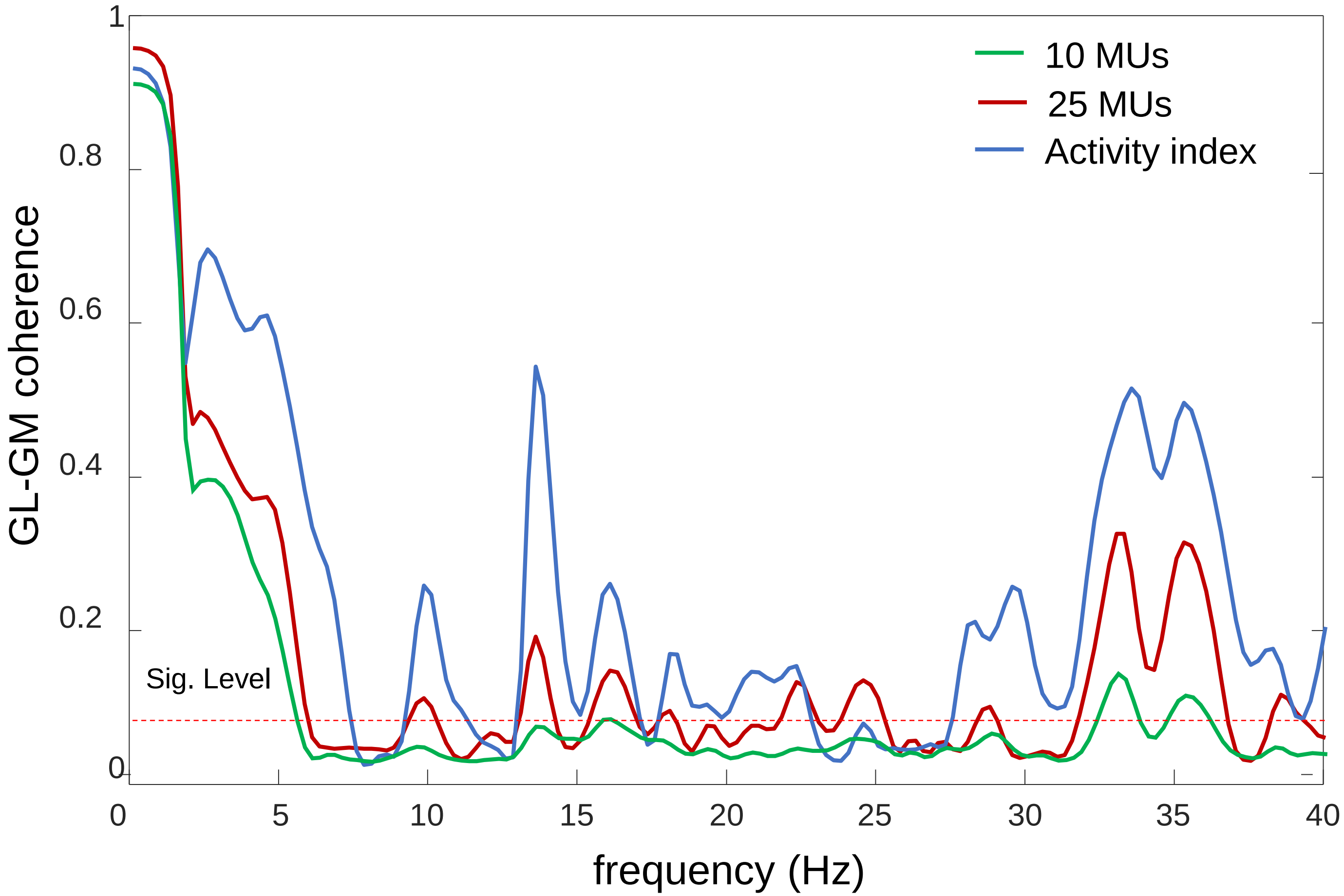
Activity index & coherence between GL and GM





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Kutoš et al. Activity index outperforms cumulative spike train and amplitude envelopes in surface EMG coherence analysis, ISEK2024.

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Segment E - Physiological assessment: Dynamic & fatiguing contractions

MUAPs are not stationary – they can change intensively & fast

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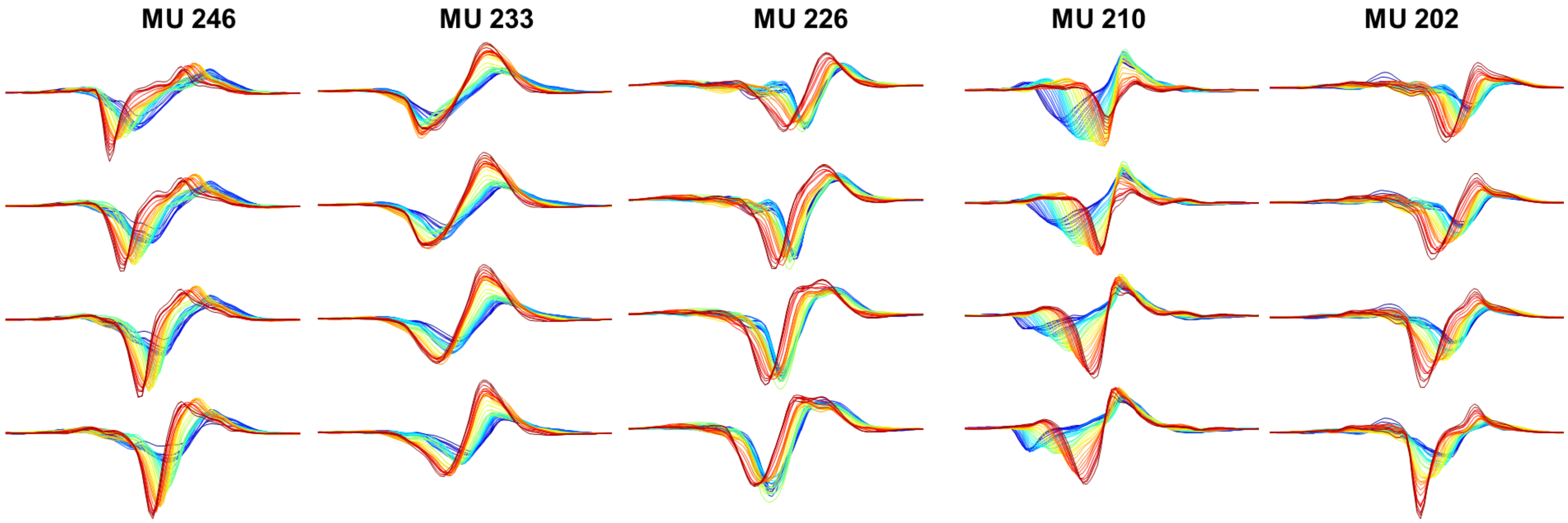
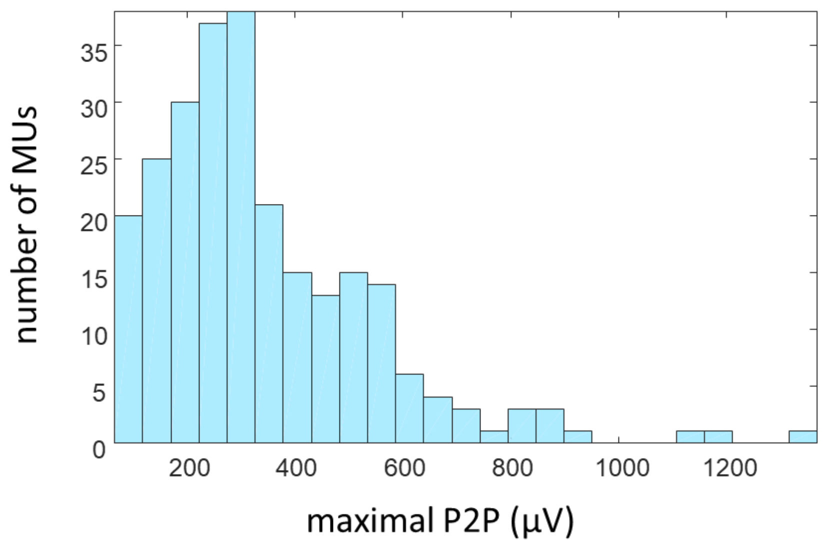
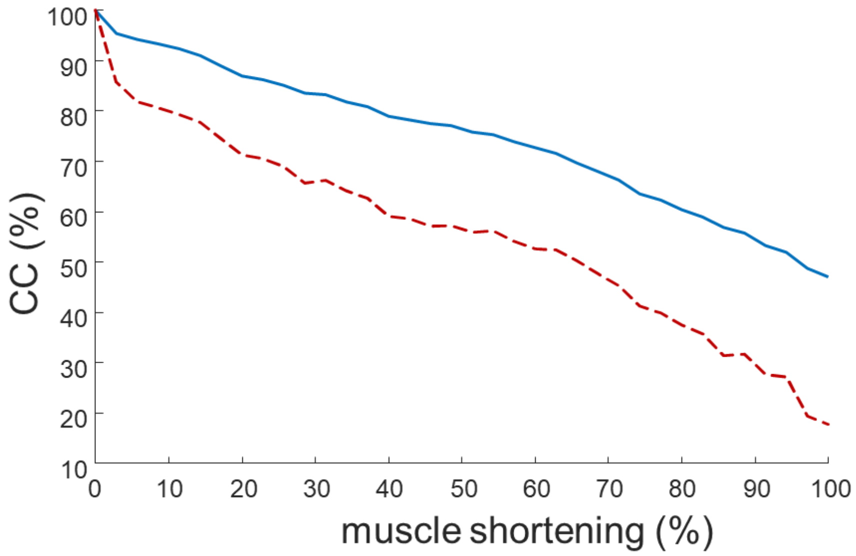
Shortening of Biceps Brachii

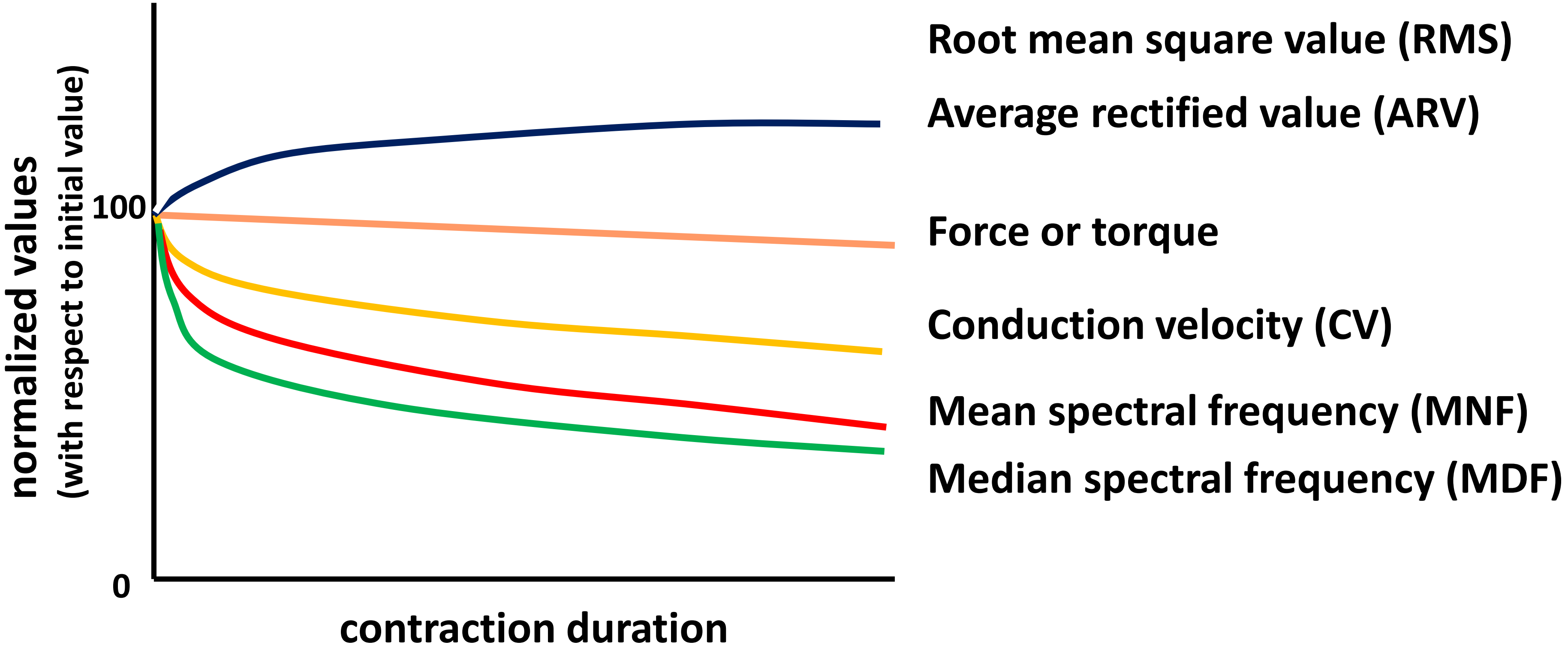






Glaser & Holobar,
IEEE TNSRE 2019

The Fatigue Plot



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

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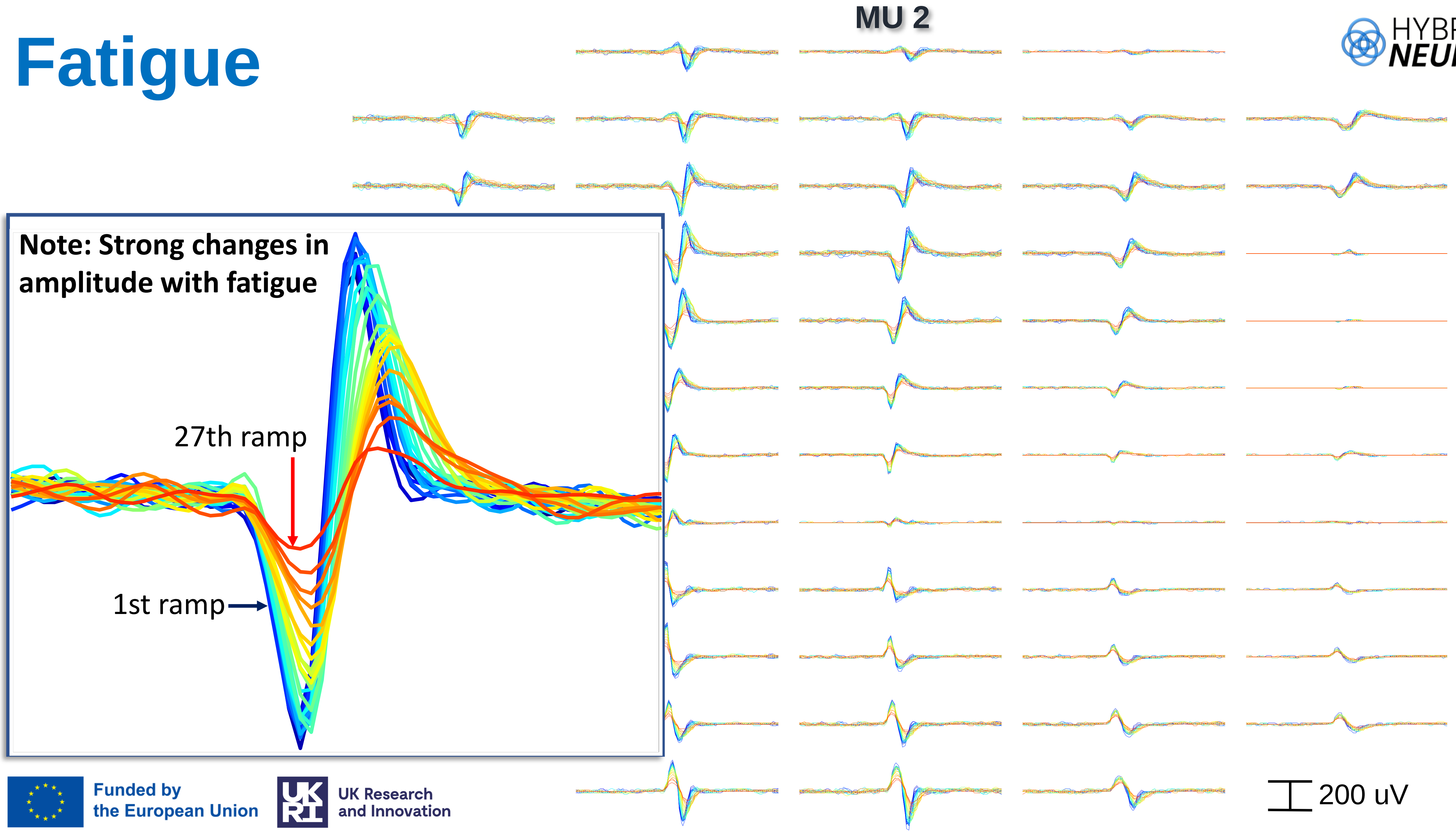
Fatigue



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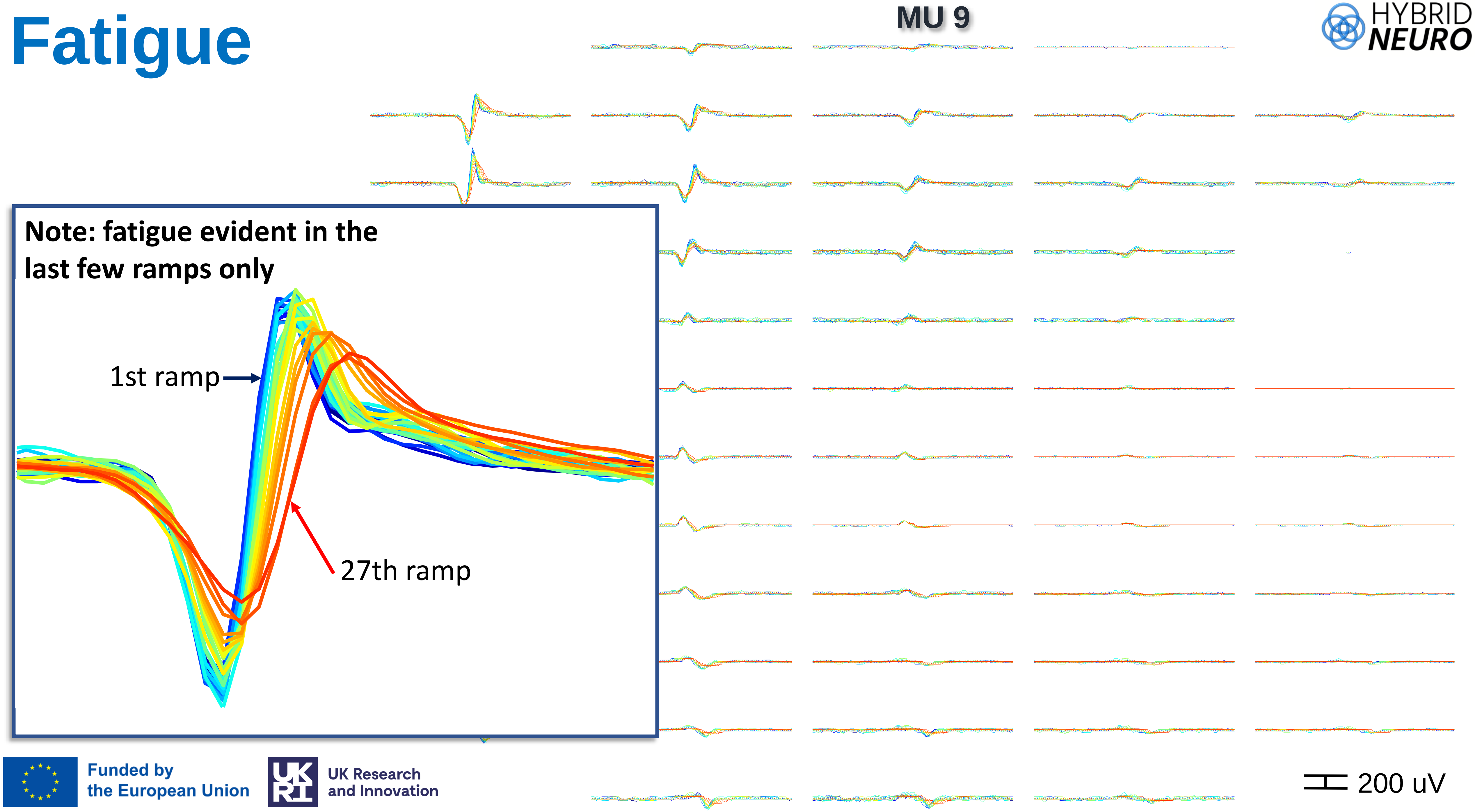
Fatigue



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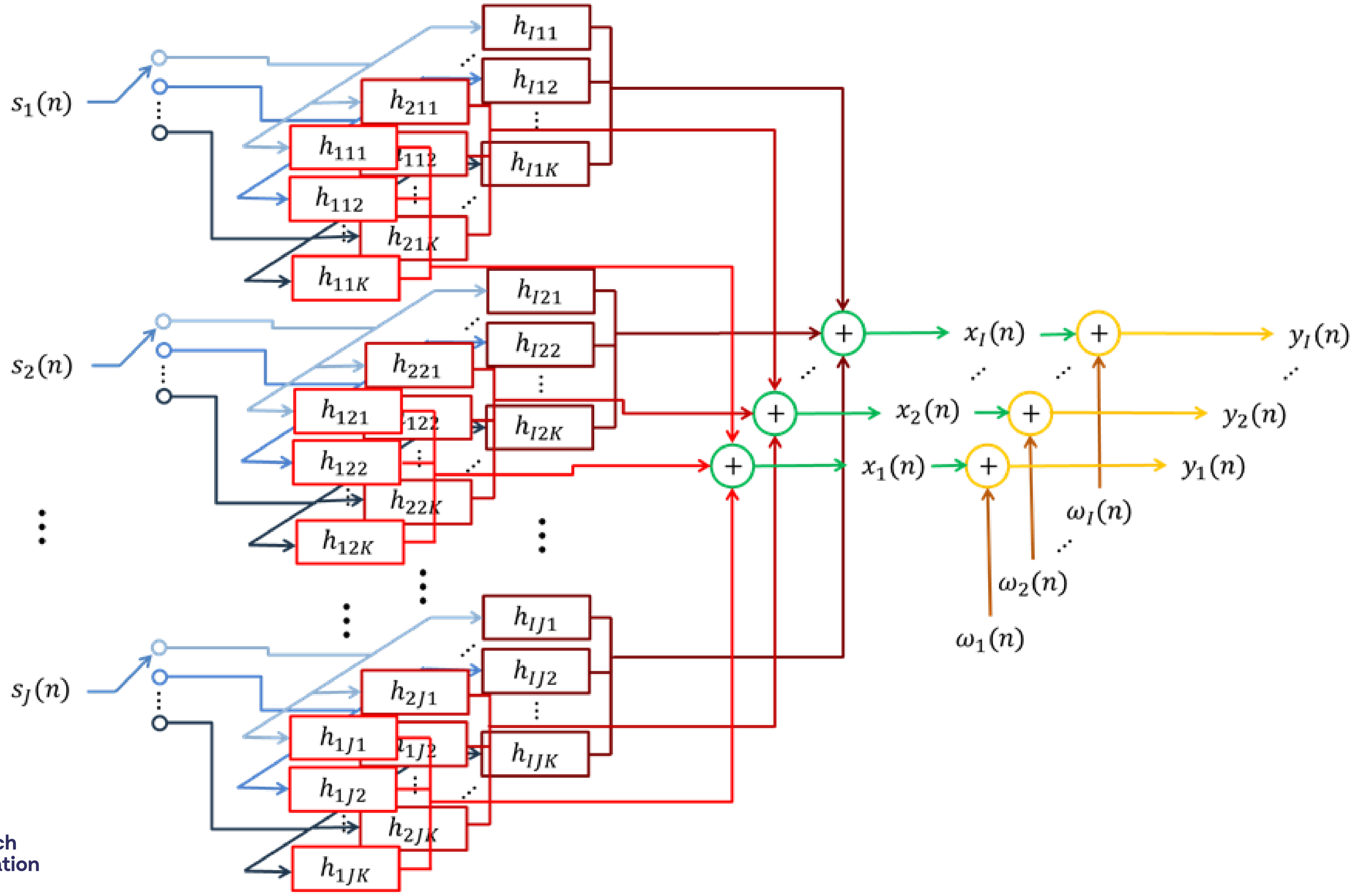
Dynamic HDEMG model

MUAPs are functions of time

- Repeated dynamic contractions: cyclostationary
- Nonrepeated dynamic or/and fatiguing contractions: nonstationary



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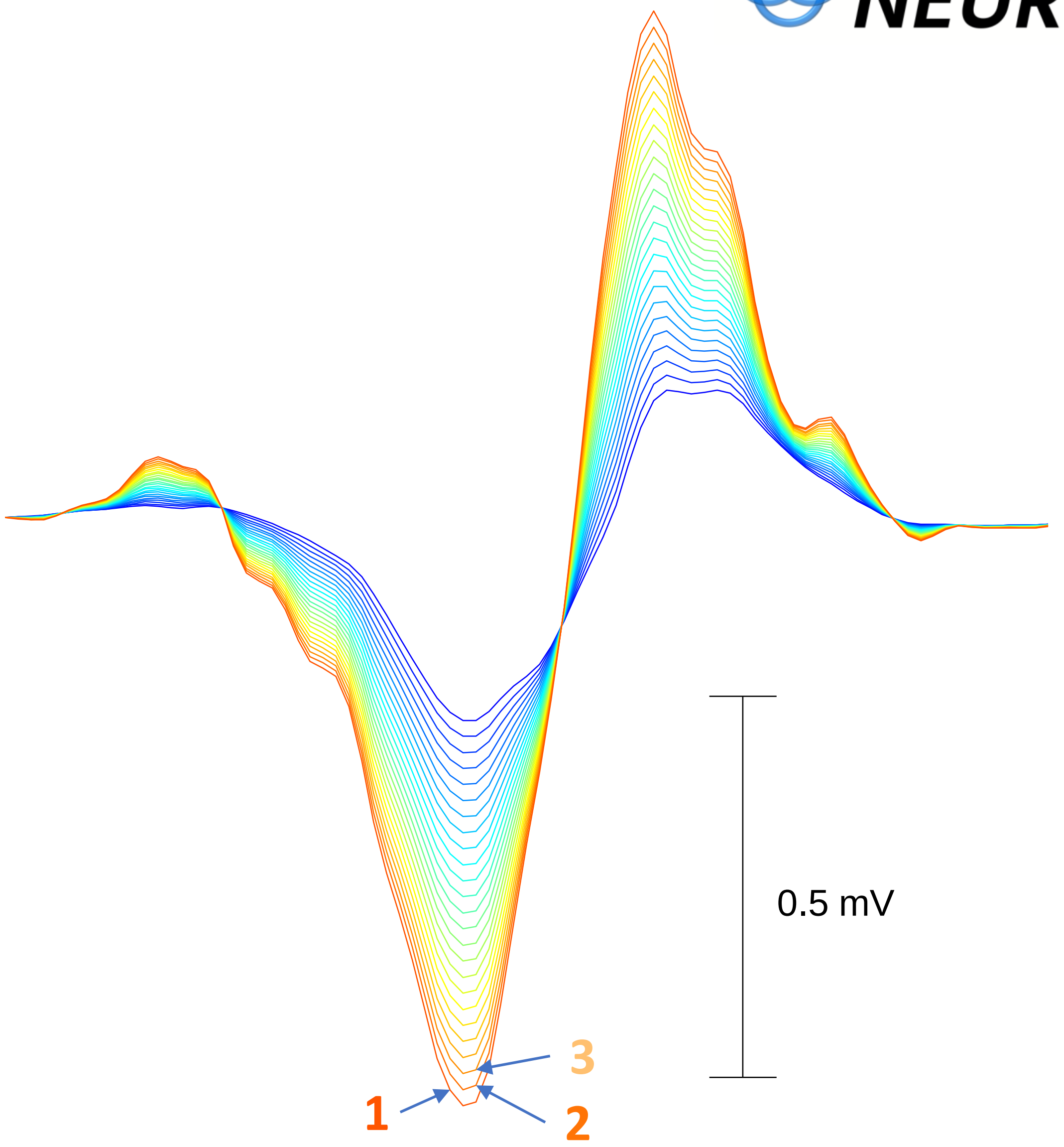
MUAP shape prediction on each HDEMG channel

Can we predict the change of MUAP based on already identified changes?

Can we integrate this prediction into MU filter?



Kramberger & Holobar, IEEE Access 2021

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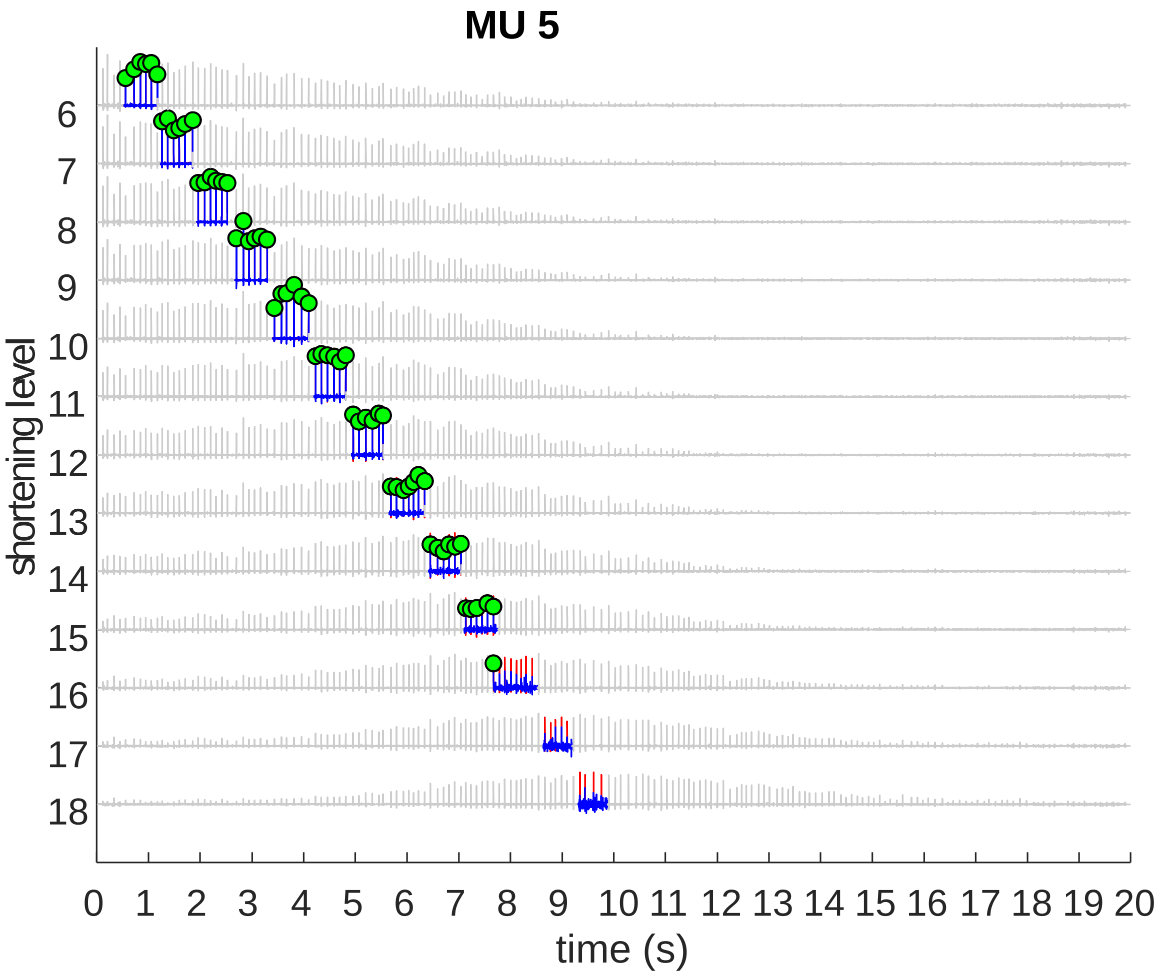
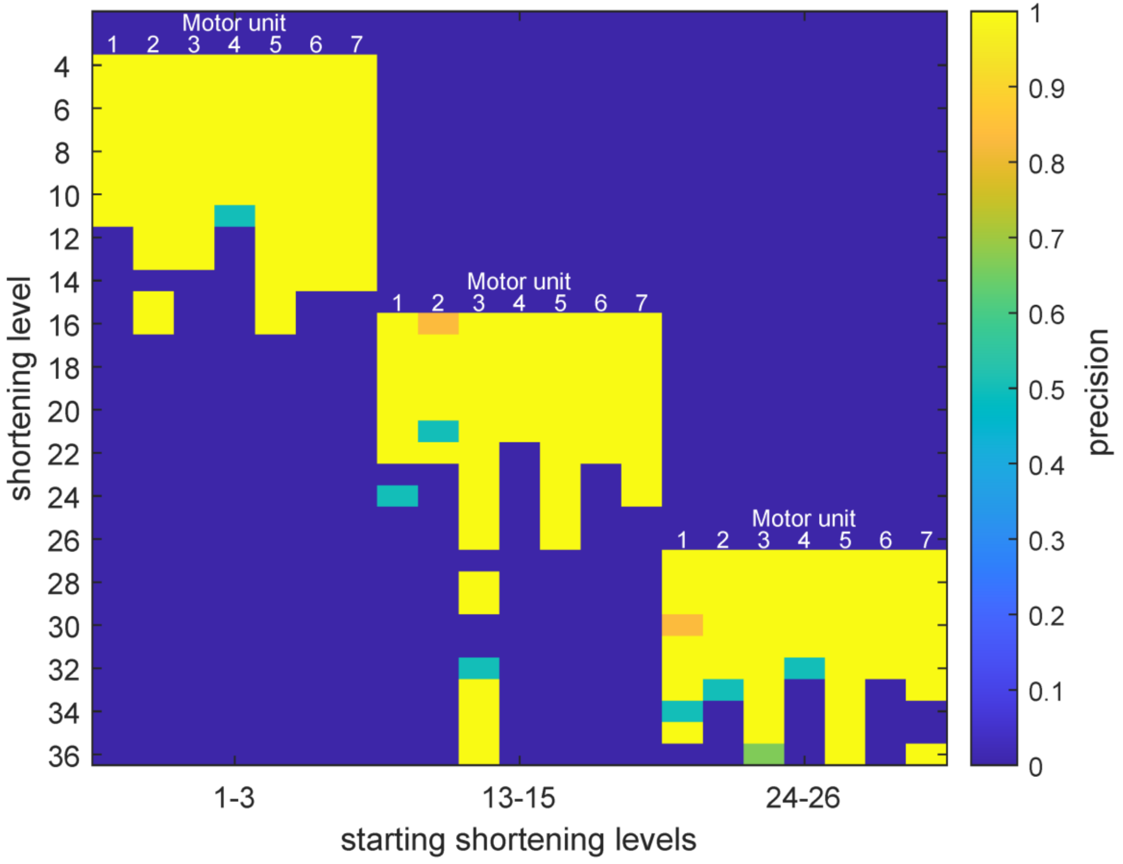
MU tracking

Kramberger & Holobar, IEEE Access 2021





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Processing pipeline

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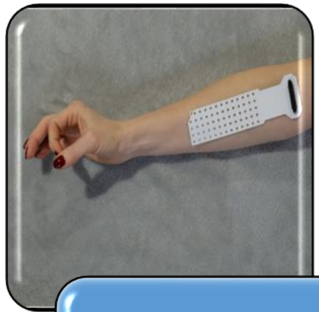
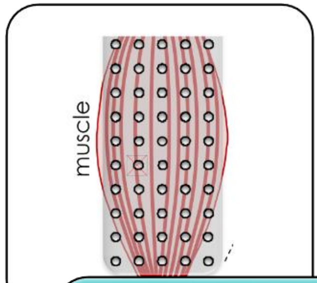
Segment A



HDEMG acquisition

5 steps

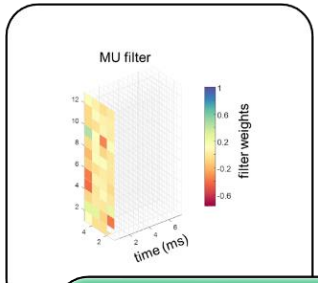
Segment B



HDEMG channel selection

5 steps

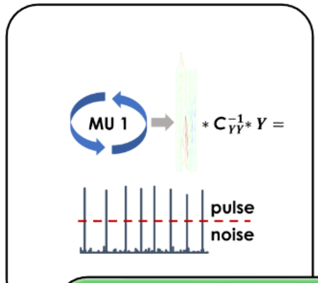
Segment C



BSS-based MU filter estimation

5 steps

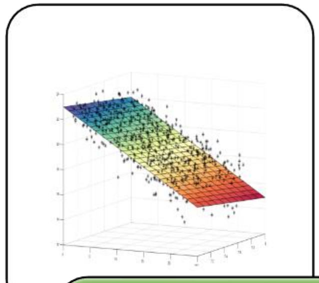
Segment D



MU filter optimization & firings segmentation

5 steps

Segment E



Physiological assessment

5 steps

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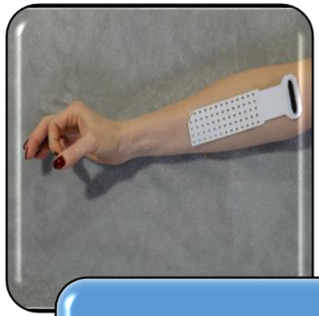
Processing pipeline

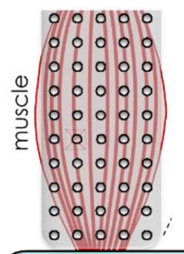
Segment A



HDEMG acquisition

5 steps

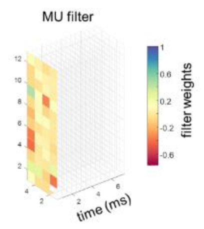
Segment B



HDEMG channel selection

5 steps

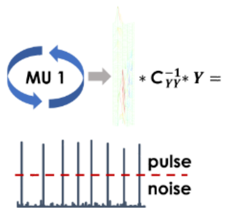
Segment C



BSS-based MU filter estimation

5 steps

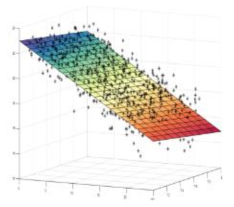
Segment D



MU filter prediction, correction & firings segmentation

5 steps

Segment E



Physiological assessment

5 steps

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Segment E - Physiological assessment: Elicited contractions

Reflexes, Electrical or Magnetic Stimulations

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Voluntary vs. elicited contraction:

MU firing patterns & EMG

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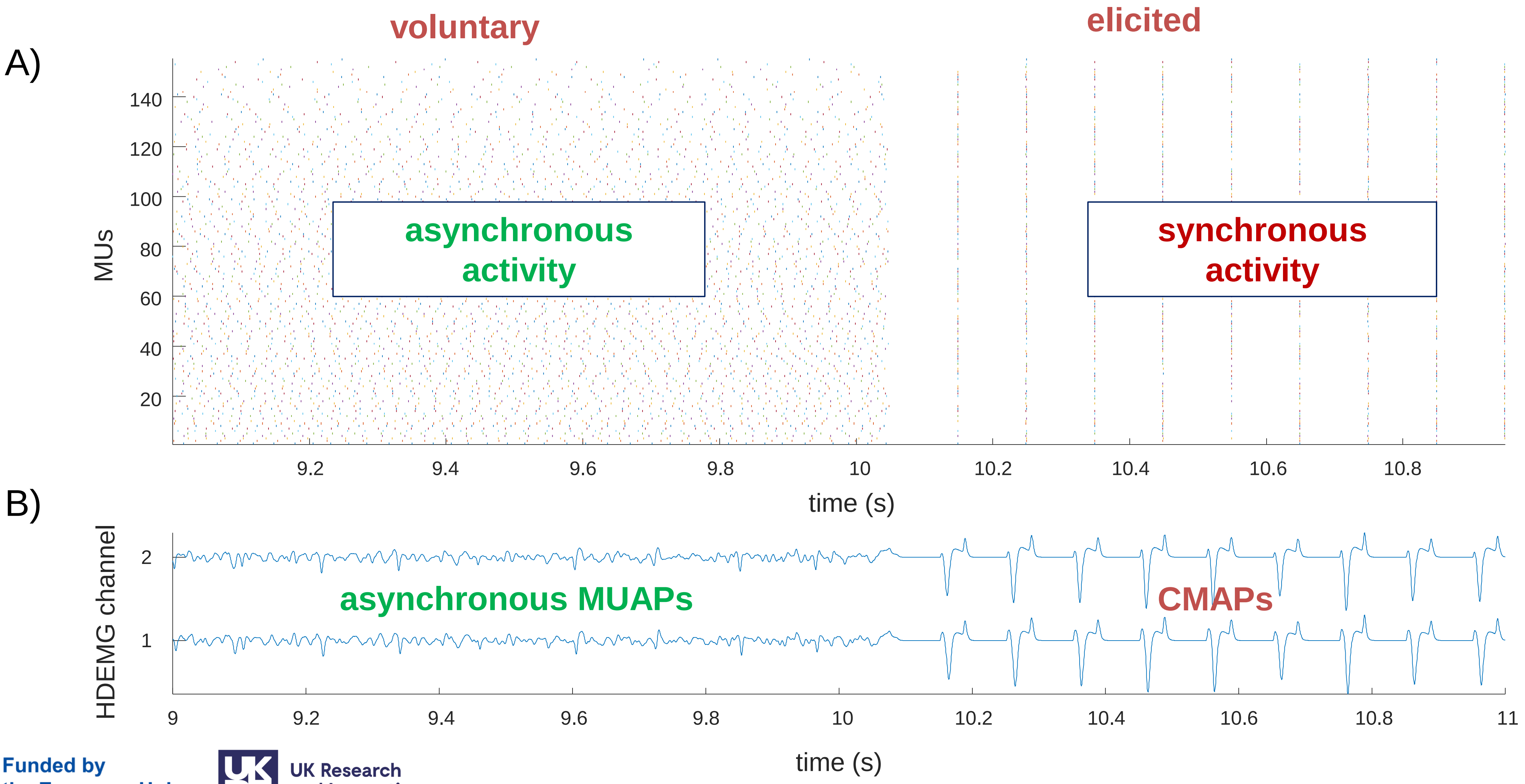

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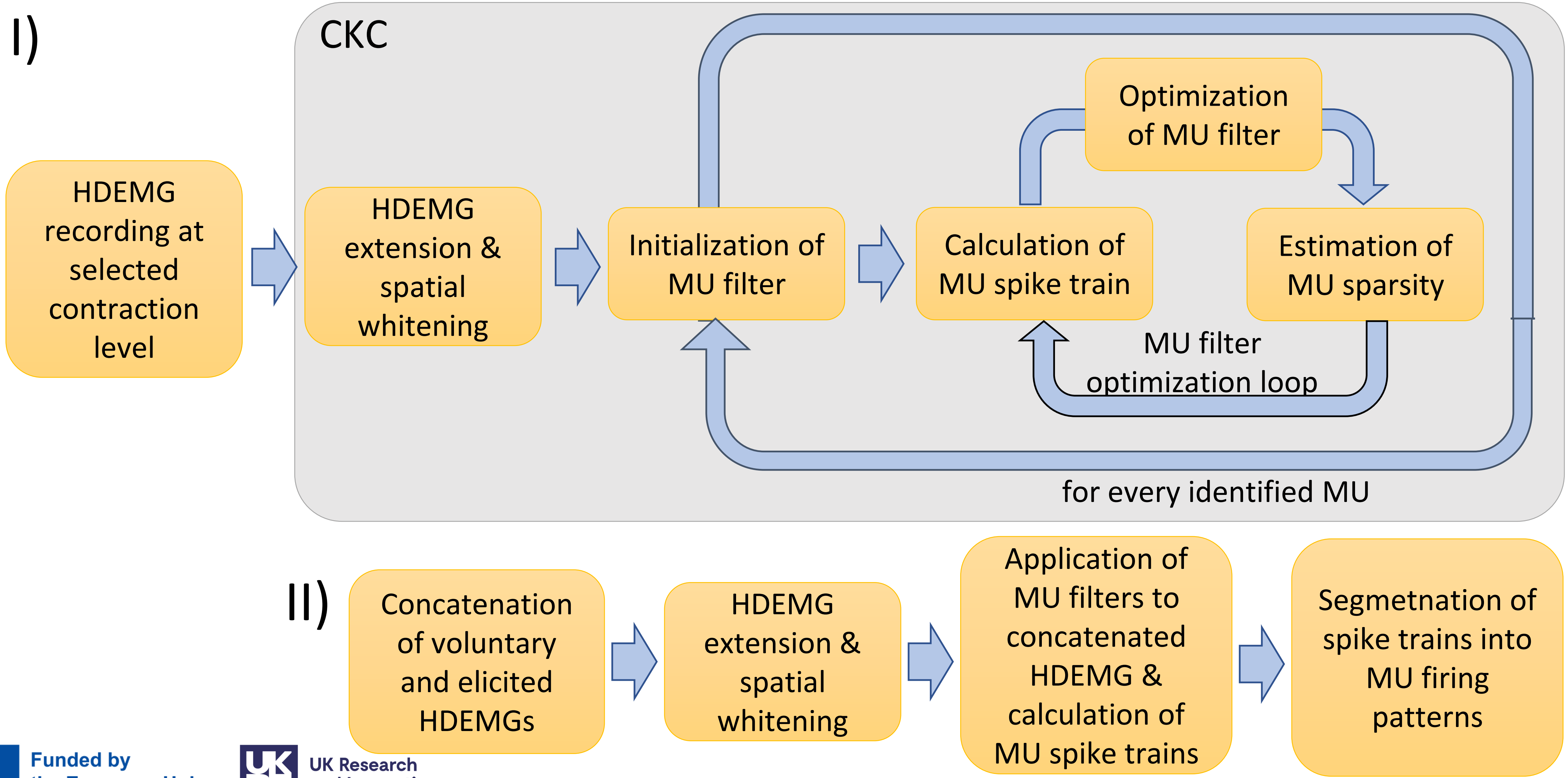
Segment C – MU filter estimation



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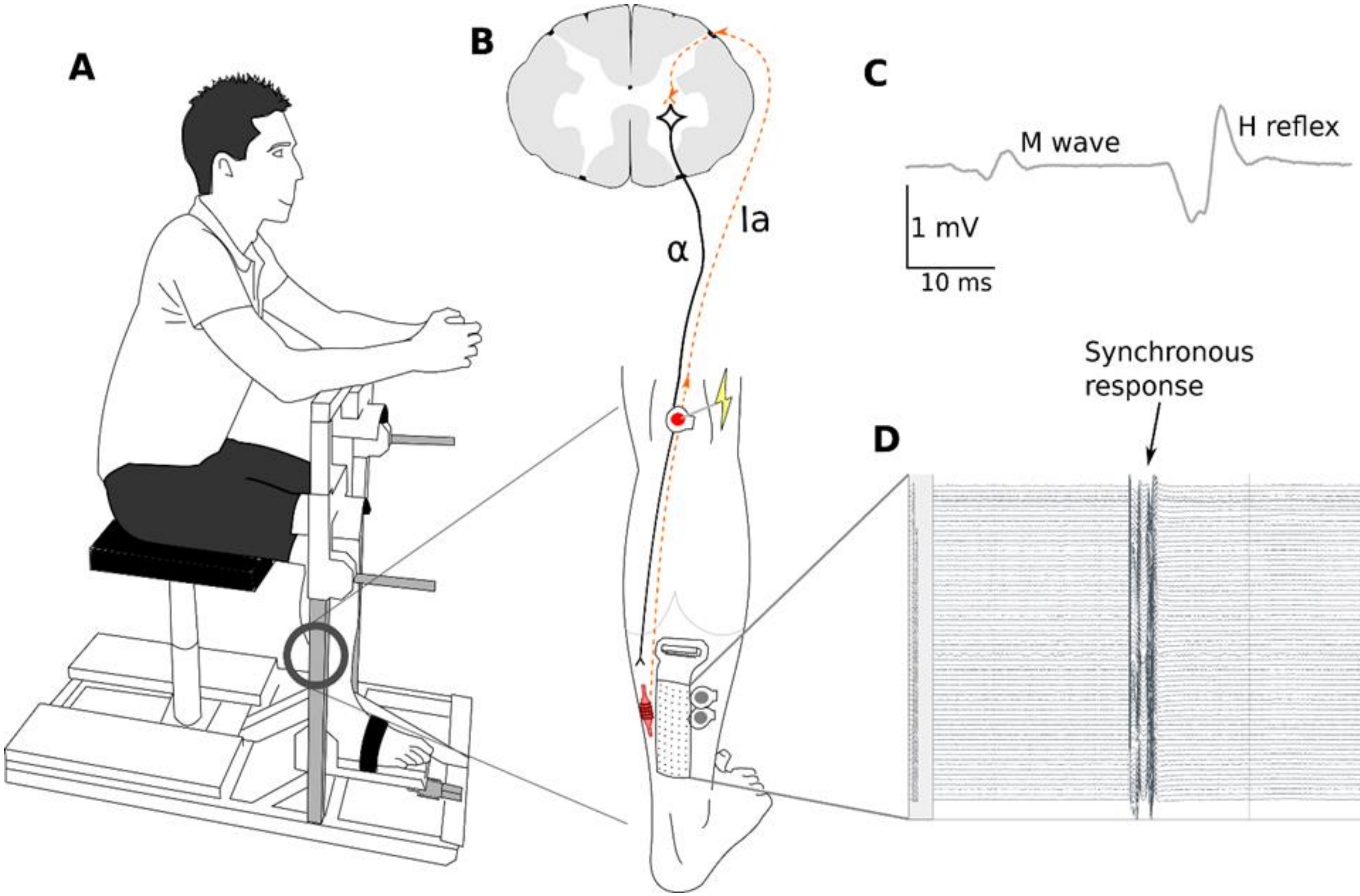
Škarabot et al. The Journal of Physiology 601, no. 10 (2023):

H reflexes – soleus

HYBRID NEURO

- 12 healthy males (33.6 ± 5.8 years, 79 ± 4.8 kg, 1,81± 0.05 m)
- HD-EMG at 5120 Hz
- Voluntary contractions
  - 10, 20, 30, 40, 50 and 70 %MVC
- Constant current high voltage stimulator
  - rectangular electrical impulses (1 ms) to the tibial nerve
- 60 H-reflexes evoked at three levels of muscle activity:
  - rest (REST)
  - plantar flexion at 10% (C10)
  - plantar flexion at 20% of MVC (C20)



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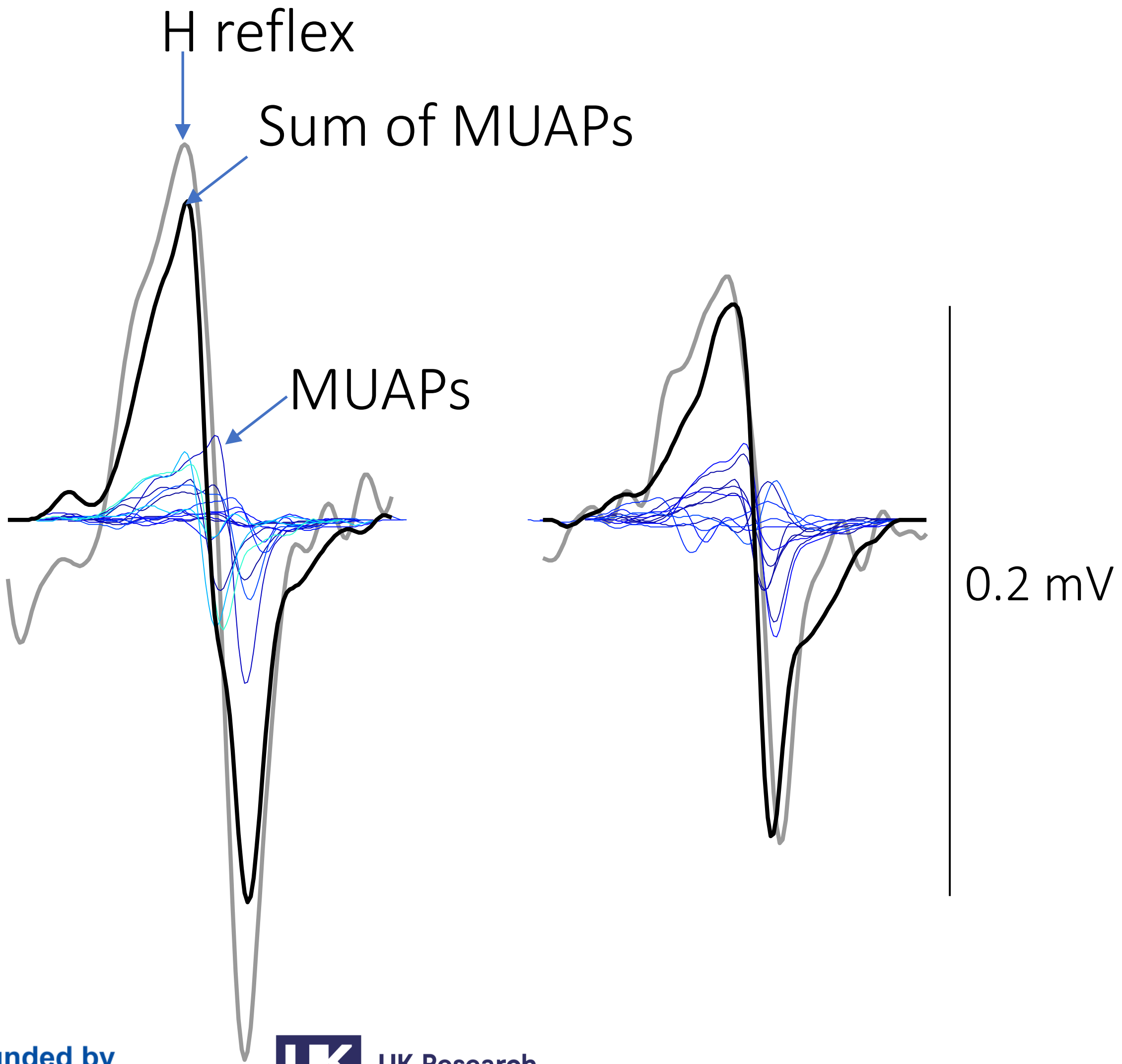
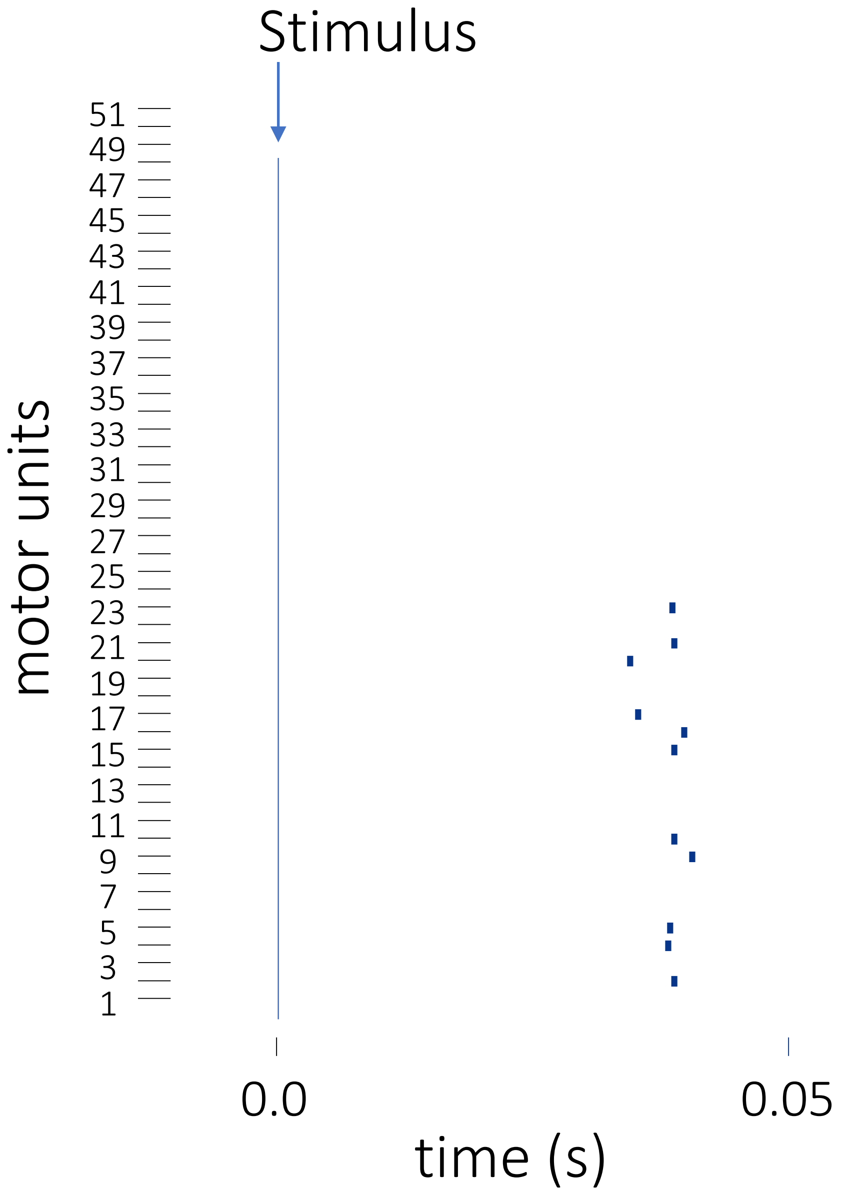
Kalc et al. IEEE Trans. on Neural Sys. and Rehab. Eng. 31 (2022)

H reflexes –soleus

Kalc et al. IEEE Trans. on Neural Sys. and Rehab. Eng. 31 (2022)





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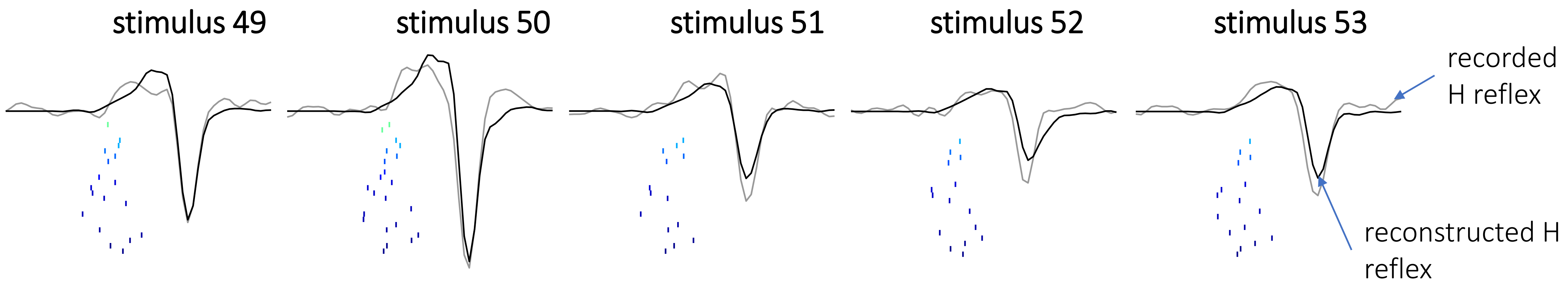
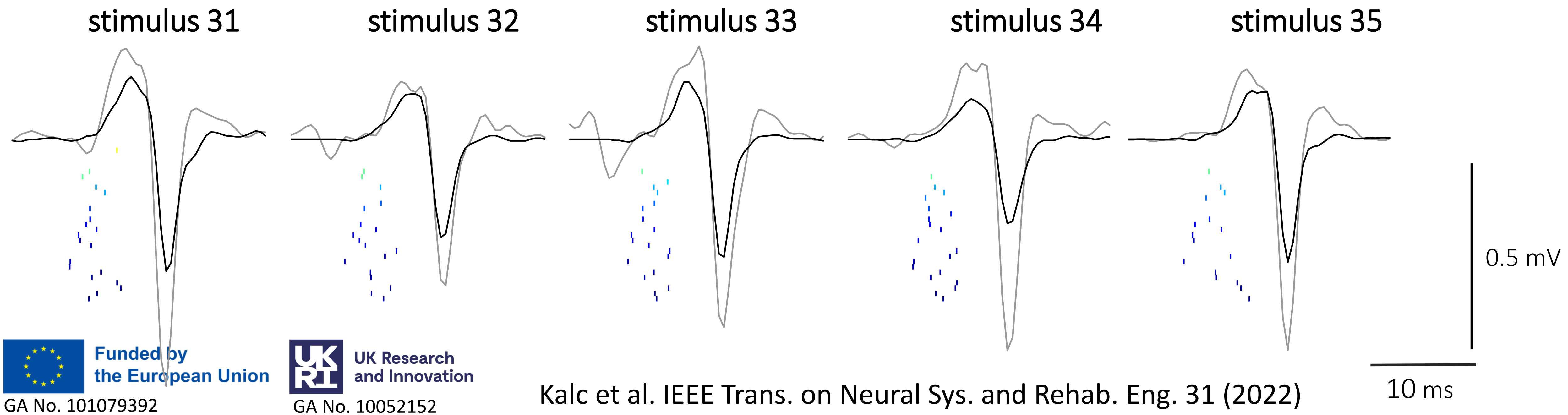
H – REST



H – 10% MVC (C10)



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Kalc et al. IEEE Trans. on Neural Sys. and Rehab. Eng. 31 (2022)

Segment F - Physiological assessment: EEG processing

Physiological Assessment & Applications

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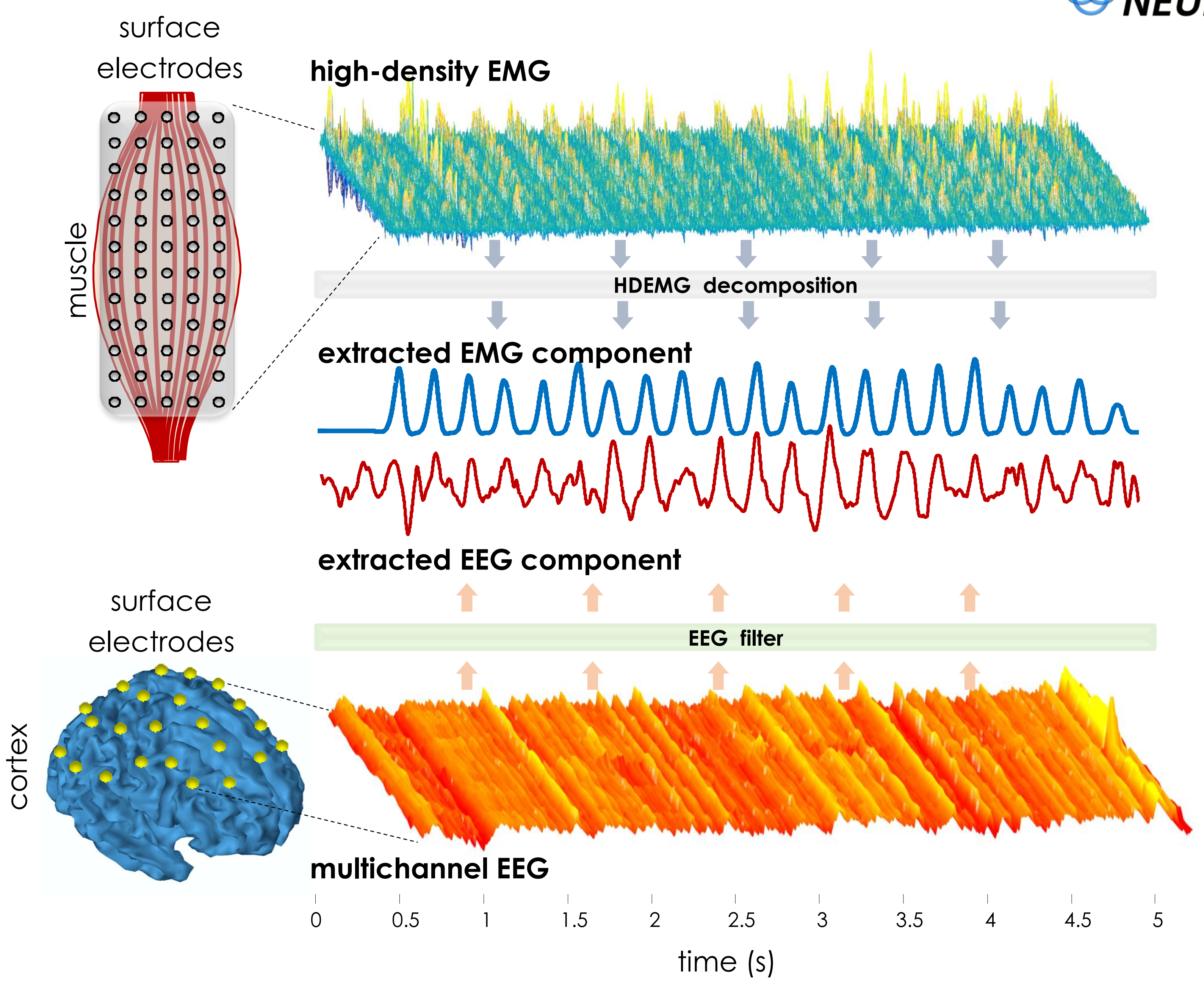
EMG & EEG: pathological tremor

Holobar & Farina: IEEE Sig. Proc. Magazine, 2021



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EMG to EEG filter transfer: pathological tremor

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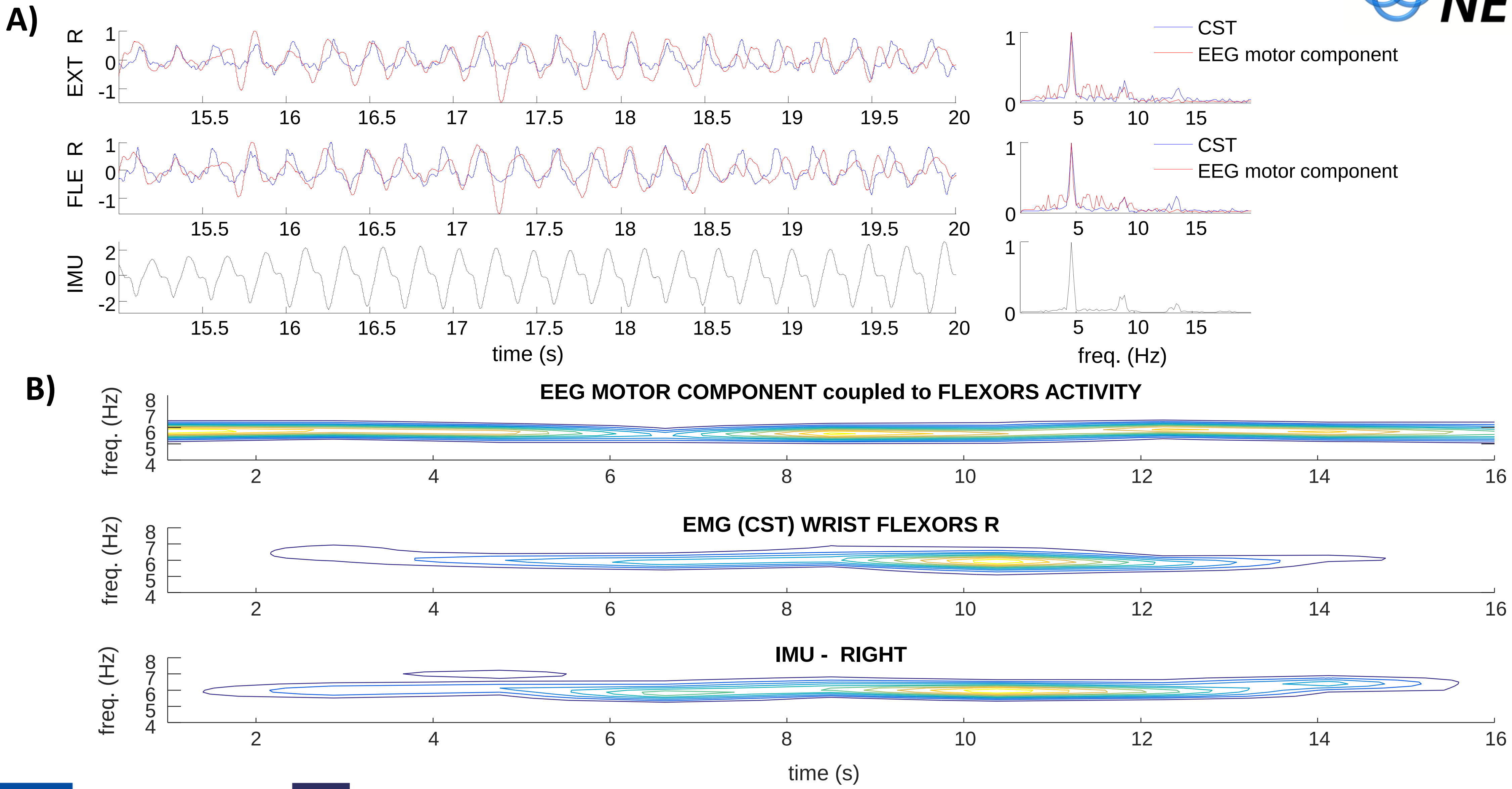

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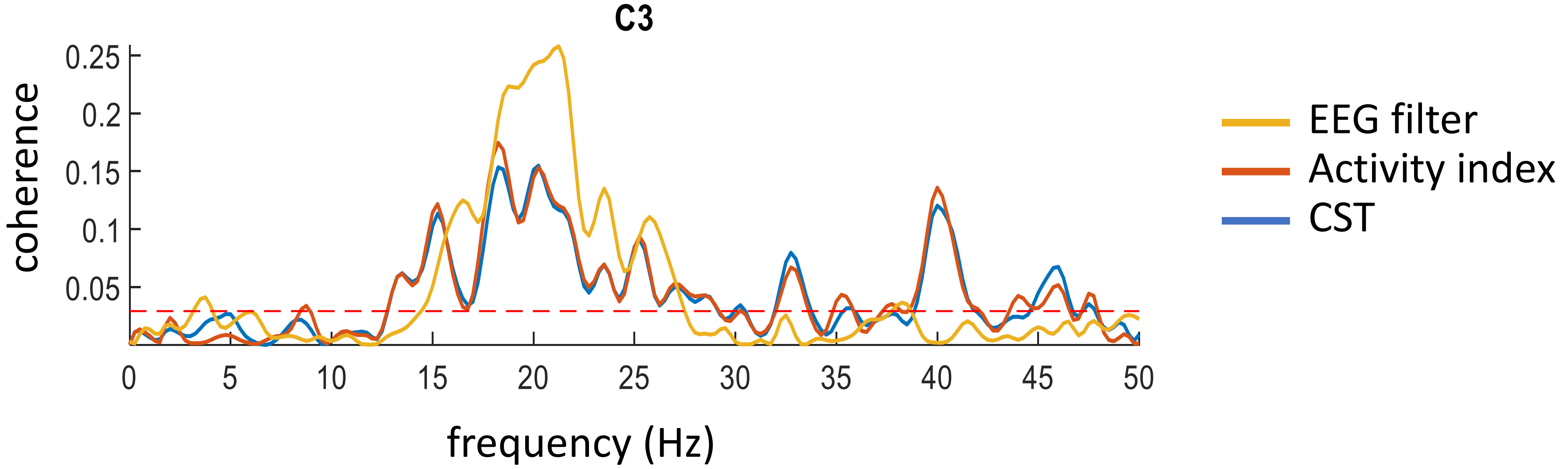
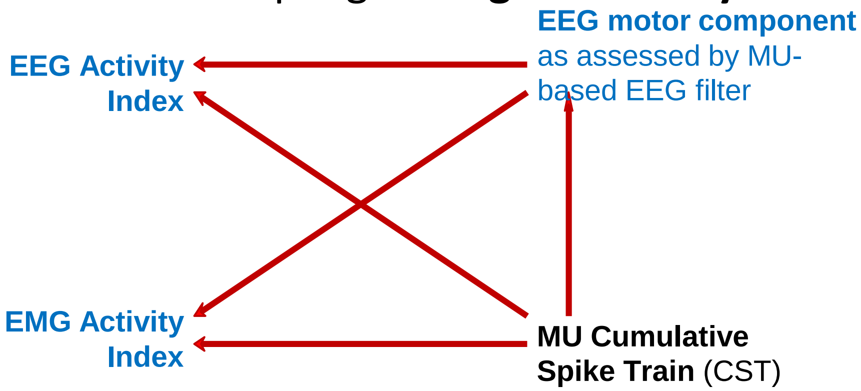
Holobar et al. Frontiers in neurology 9 (2018)

MU-based EEG filters & MU Activity Index

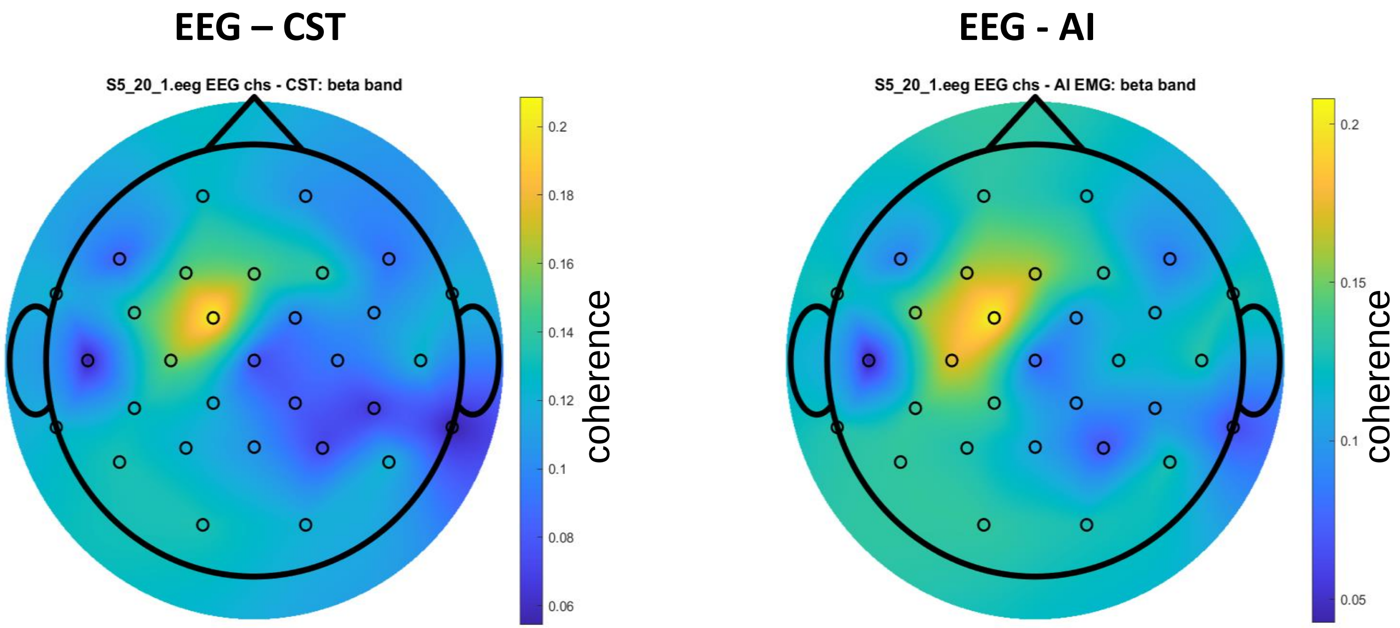
A)



B) Connectivity measurement of cortico-muscular coupling: **Granger causality**



C)



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CONCLUSIONS

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- HDEMG processing pipelines are relatively complex & contain main parameters
- Well defined quality measures support informative parameter selection
- Different steps/segments of pipelines updated independently
- Pipelines need to be adapted to the signal acquisition conditions (isometric, dynamic, elicited).
- „Per aspera ad astra“ in all the pipeline‘s segments

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Questions?

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