



# Open-source software to decompose and edit EMG signals

**Simon Avrillon, Imperial College London**

**Julien Rossato, Foundation Santa Lucia, Italy**

**Ciara Gibbs, Imperial College London, UK**

**Arnault Caillet, Imperial College London, UK**

**François Hug, Université Côte d'Azur, France**

**Dario Farina, Imperial College London, UK**

**INNOVATIONS IN EMG RECORDINGS**

**OFFLINE DECOMPOSITION**

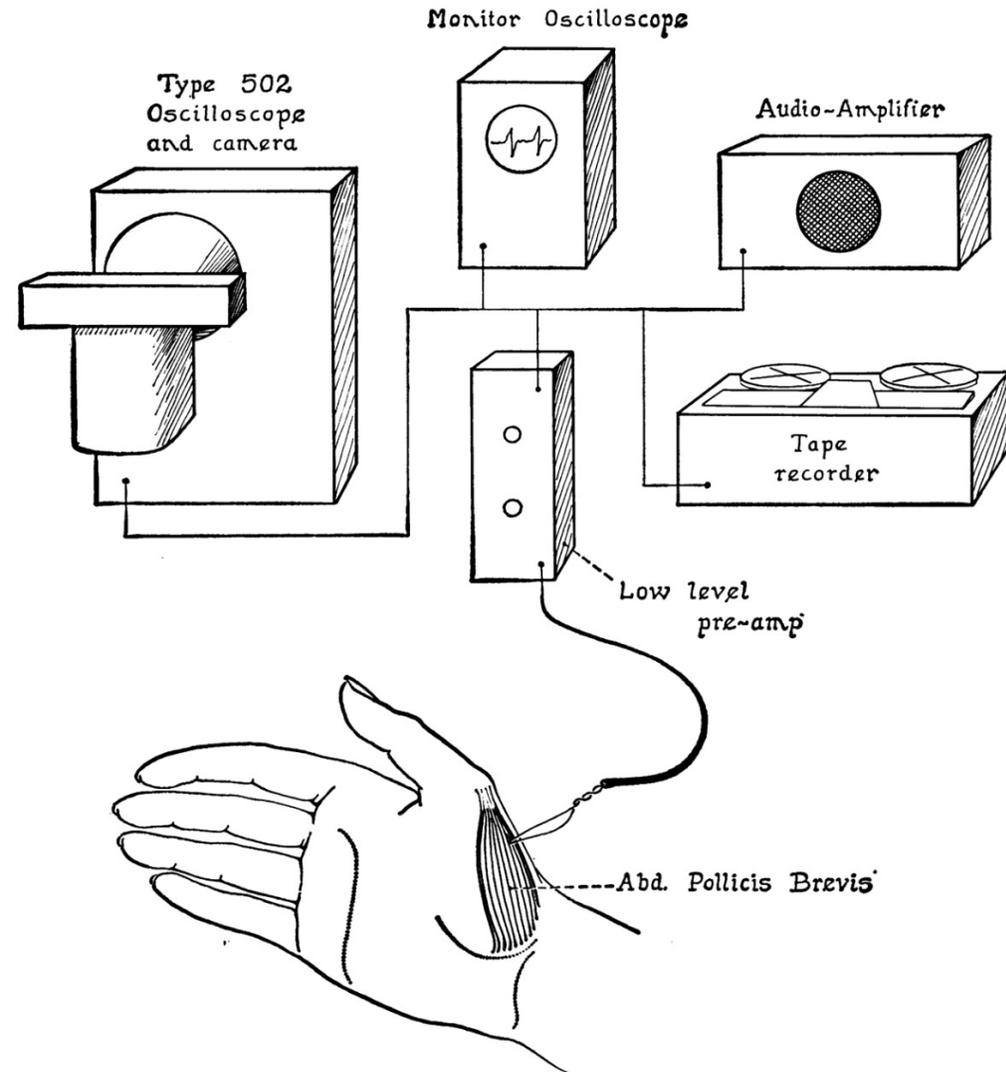
**ONLINE DECOMPOSITION**

# **INNOVATIONS IN EMG RECORDINGS**

**OFFLINE DECOMPOSITION**

**ONLINE DECOMPOSITION**

# INTRODUCTION



Basmajian (1963) Science

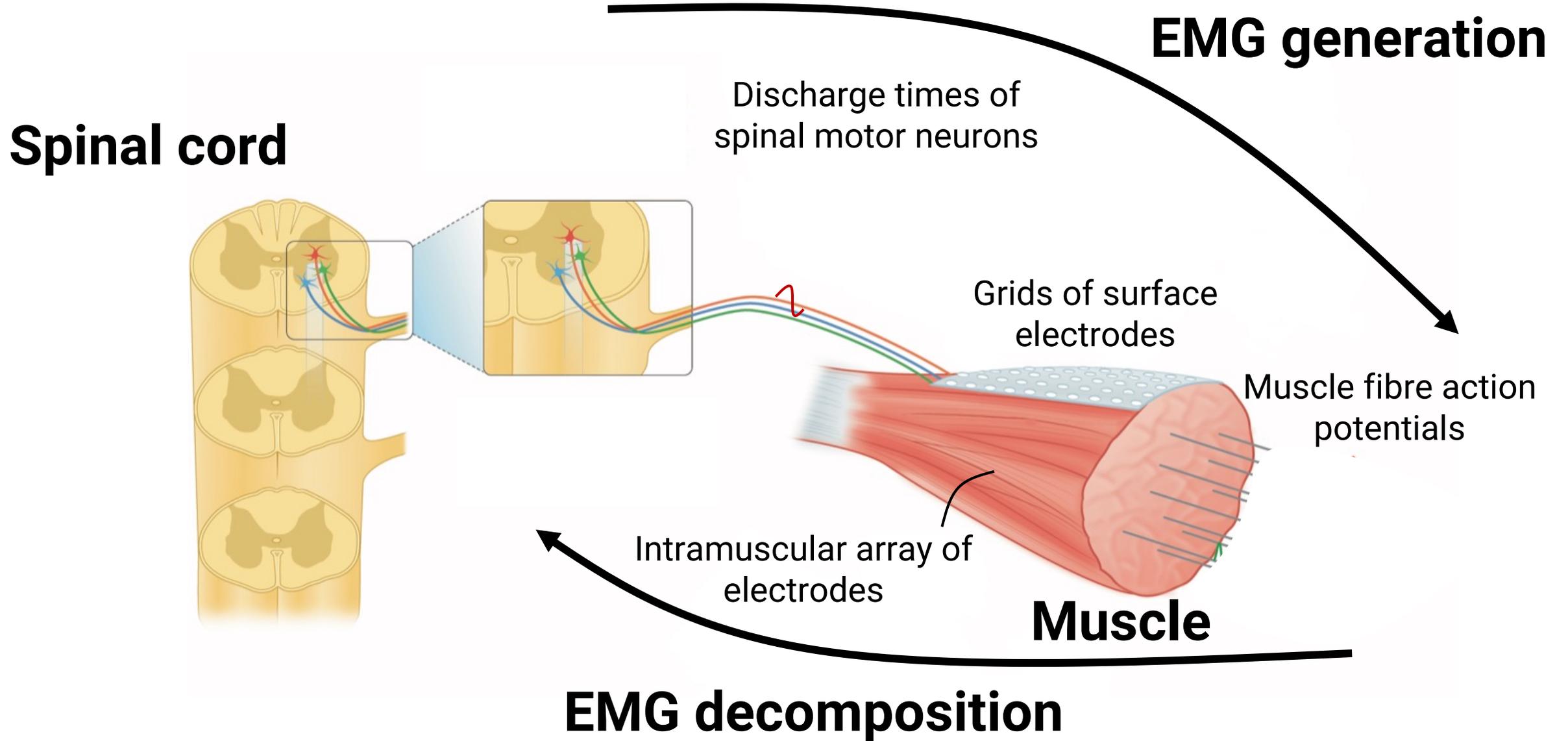
Skilled independent control of individual motor units  
via a non-invasive neuromuscular-machine interface

*E. Formento\*, P. Botros\*, J. M. Carmena*  
*University of California, Berkeley*

Video 1: Center-out task,  
last day of training

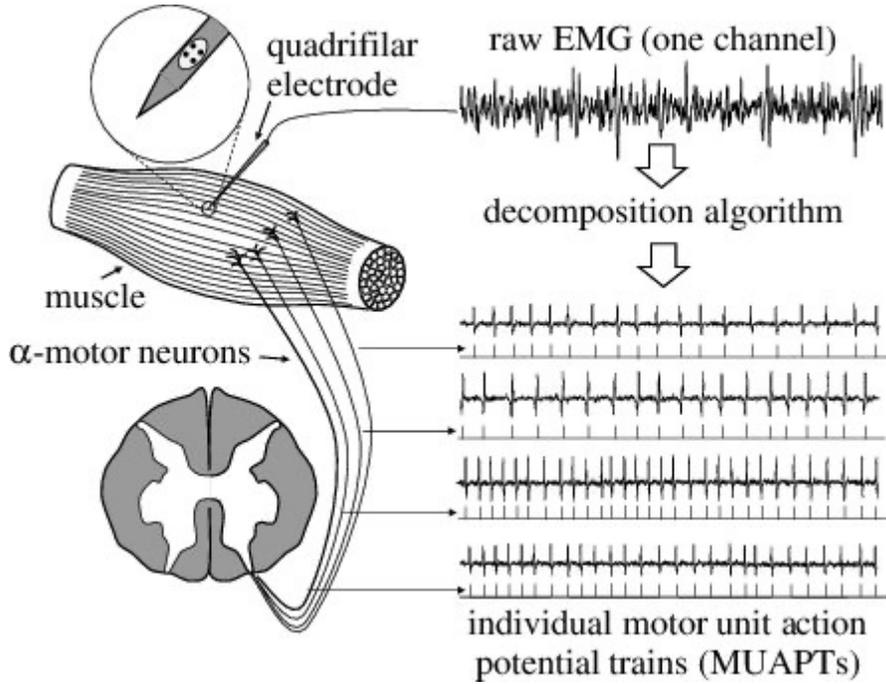
Barsakcioglu et al. (2021) IEEE Trans Biomed Eng  
Formento et al. (2021) J Neural Eng

# DECOMPOSITION OF EMG SIGNALS



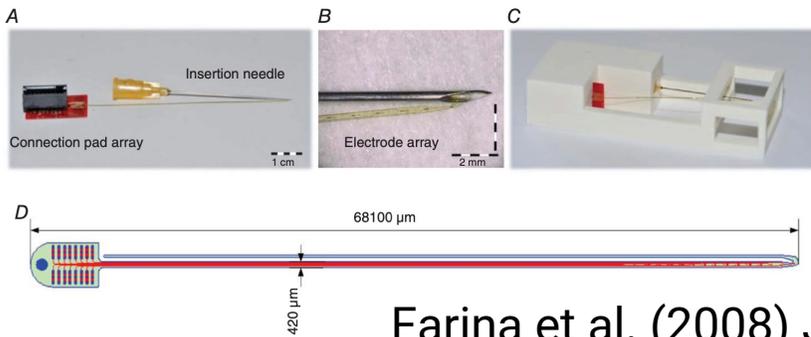
# INTRODUCTION

## Quadrifilar needle electrodes



De Luca & Forrest (1972) IEEE Trans Biomed Eng

## Intramuscular electrodes on thin films



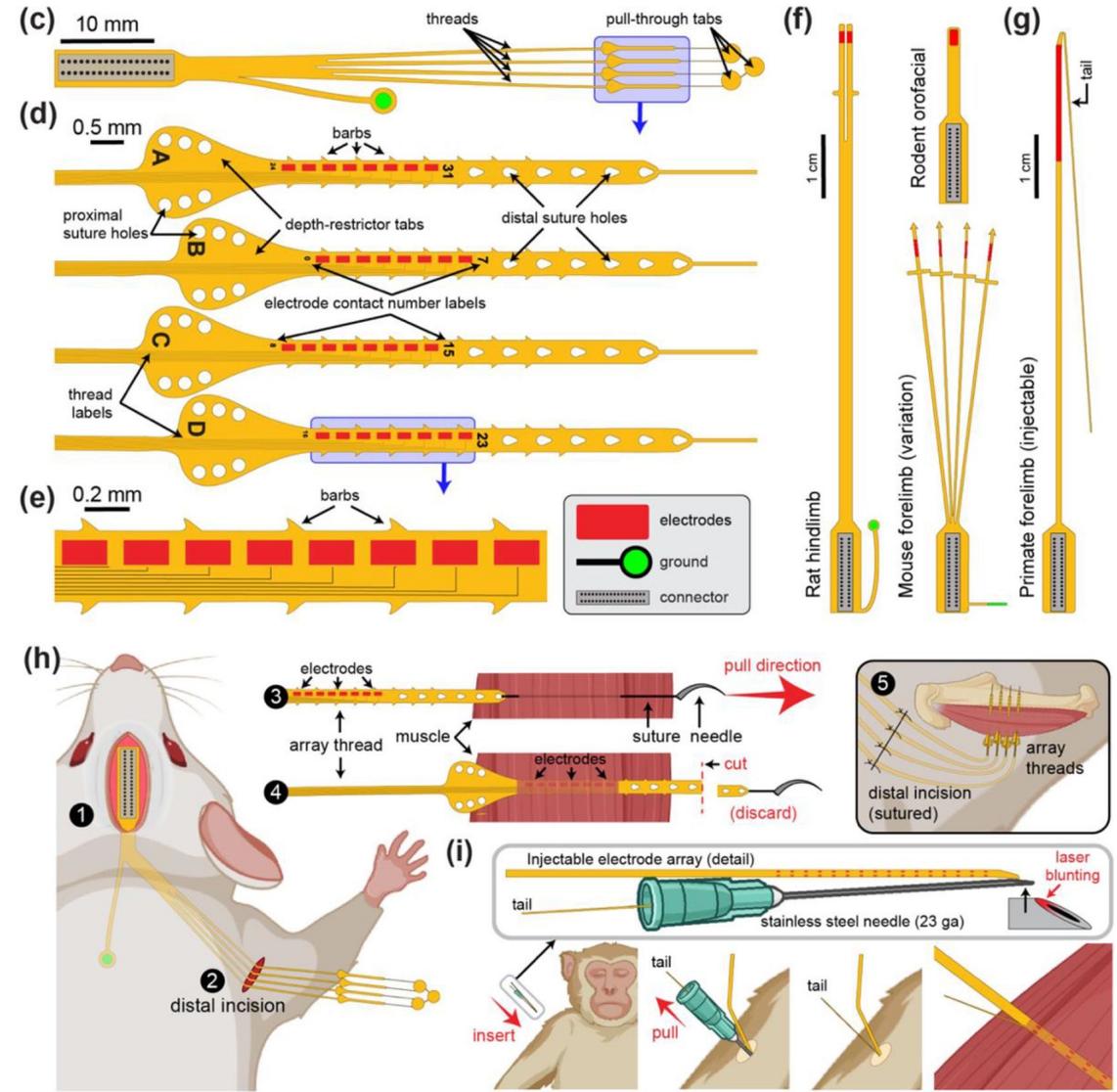
Muceli et al. (2015)  
J Physiol

Muceli et al. (2022)  
Sci Adv

Farina et al. (2008) J Neurophysiol

6

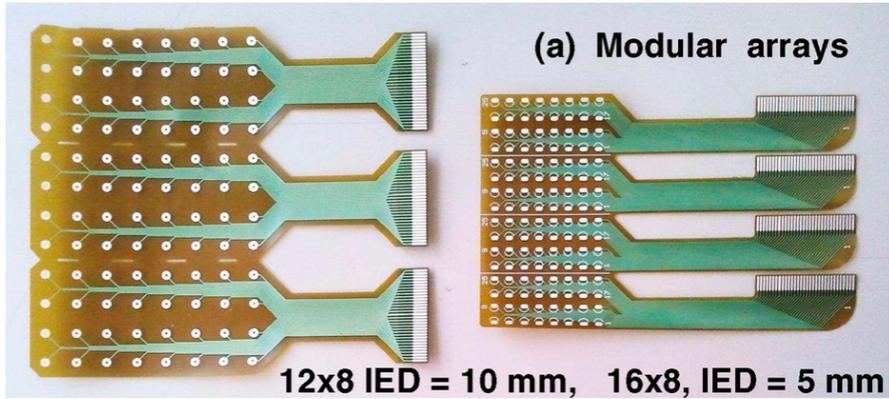
## Myomatrix array



Chung et al. (2023) Elife

# EVOLUTION OF EMG RECORDING METHODS

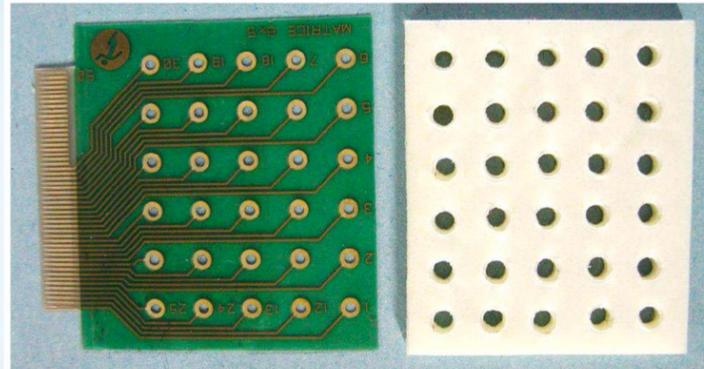
## Arrays of surface electrodes



(c) Wearable and modular 64/128 channel amplifier with sleeve electrode array

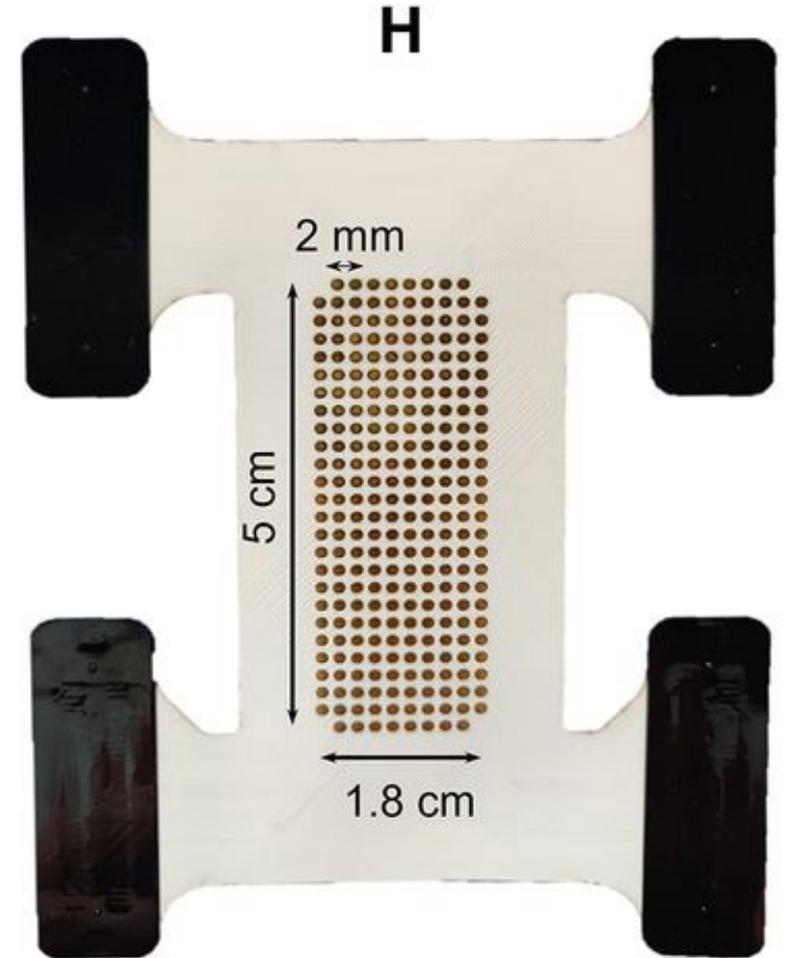


(d) Flexible mylar array with double adhesive foam.



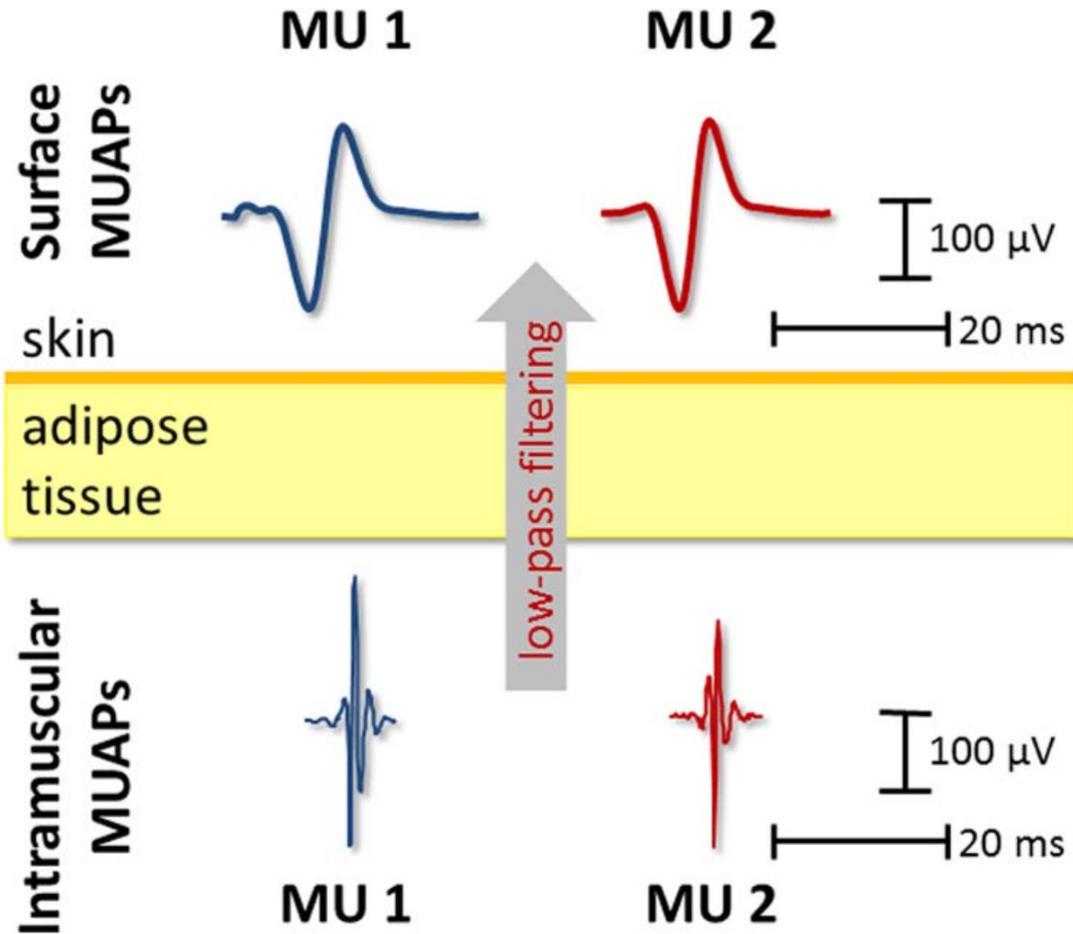
Merletti et al. (2017)

## Ultra-dense grids

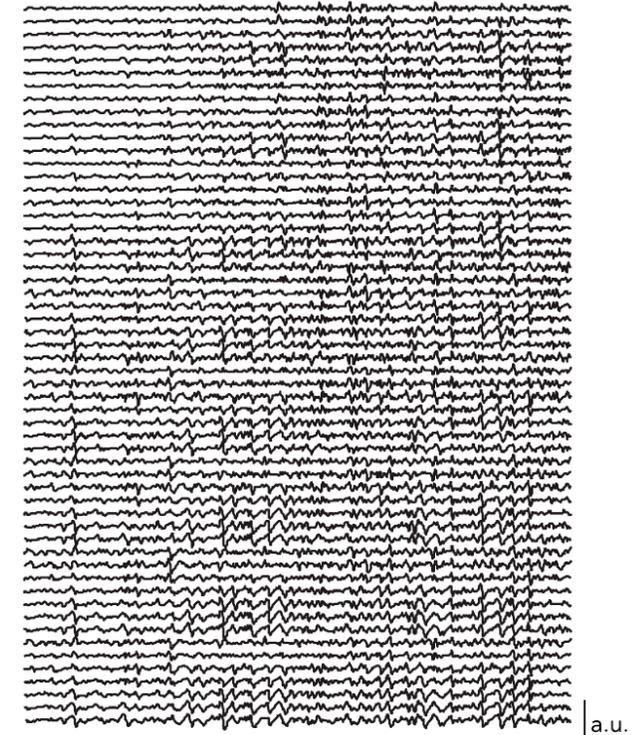
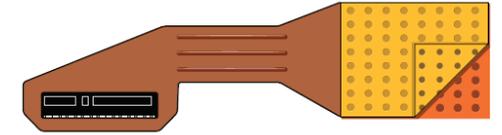
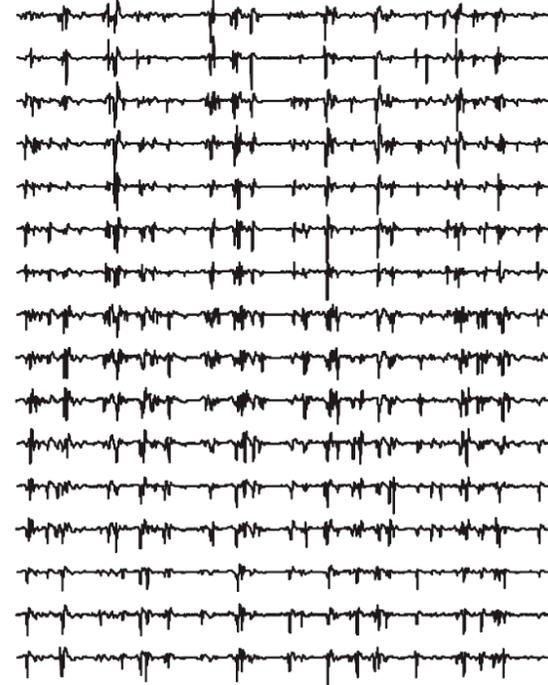
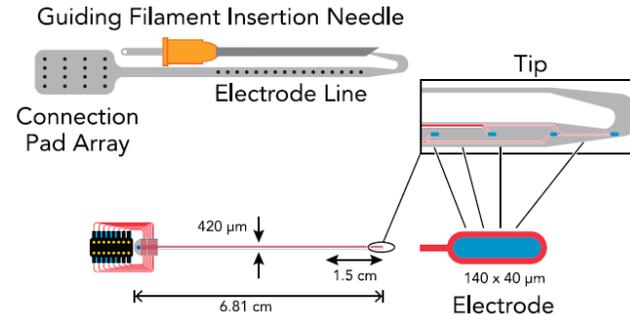


Caillet et al. (2023) eNeuro

# EFFECT OF THE VOLUME CONDUCTOR

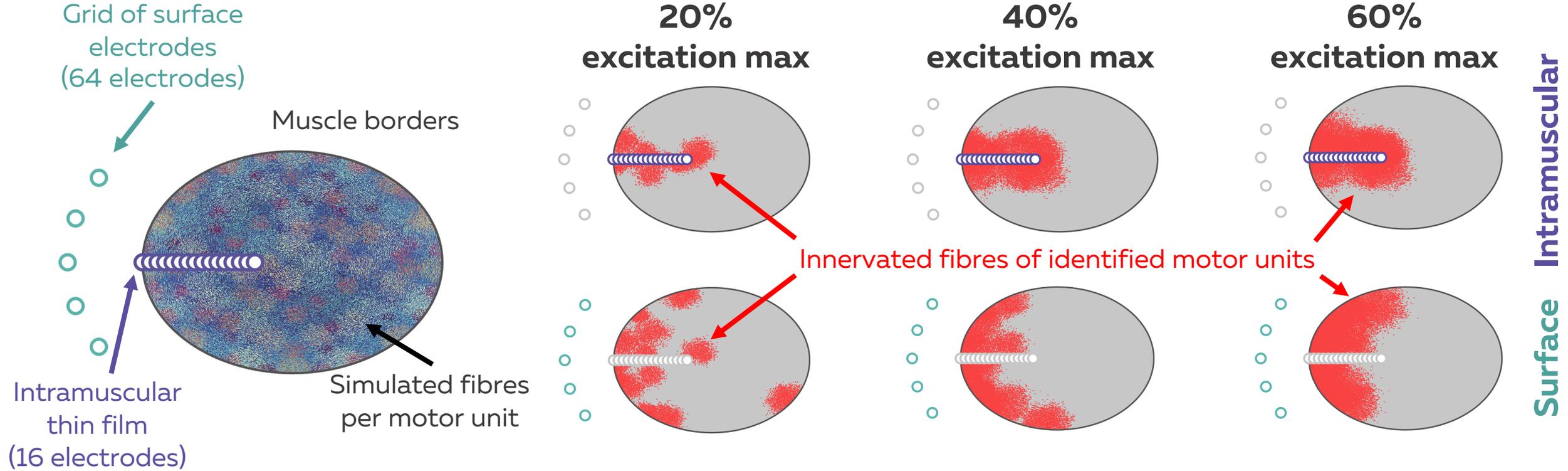


Farina & Holobar (2016) Proceedings of the IEEE



Farina et al. (2016) Physiology

# EFFECT OF THE VOLUME CONDUCTOR



## Change in muscle geometry



## Drift



INNOVATIONS IN EMG RECORDINGS

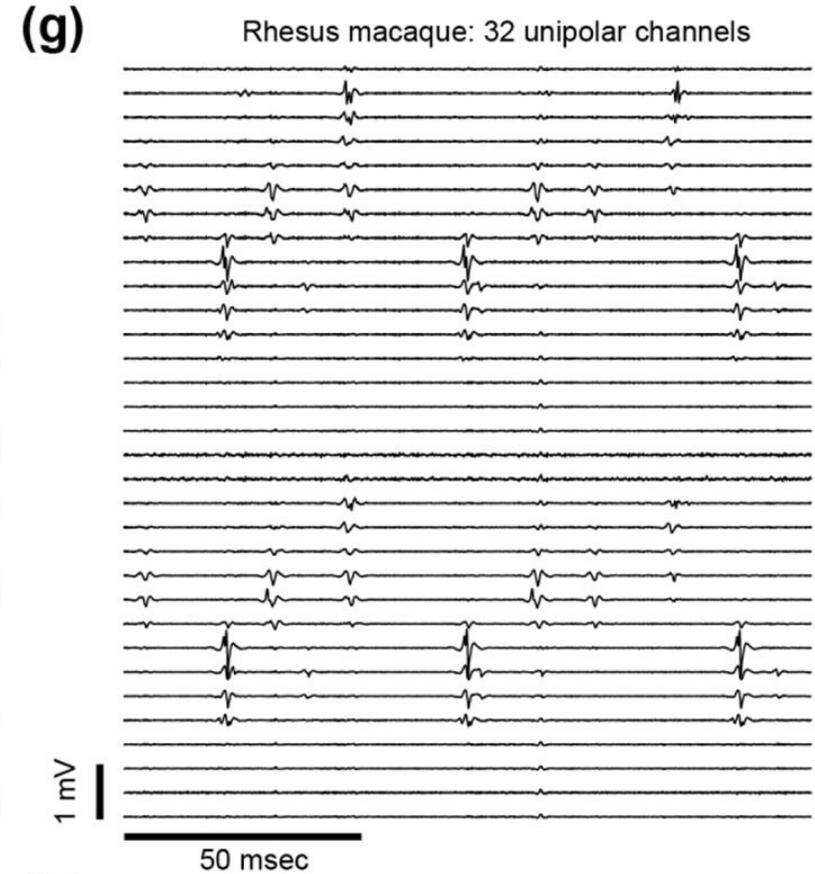
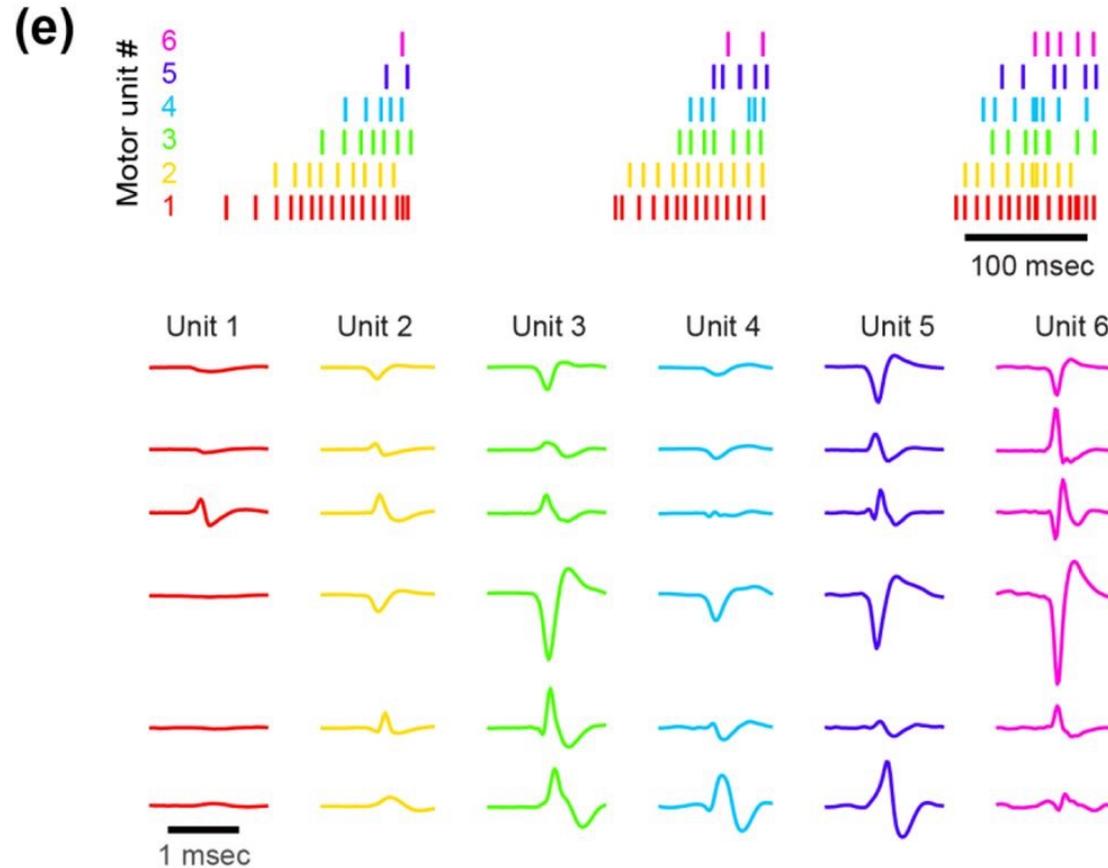
**OFFLINE DECOMPOSITION**

ONLINE DECOMPOSITION

# SPIKE SORTING FOR INTRAMUSCULAR EMG

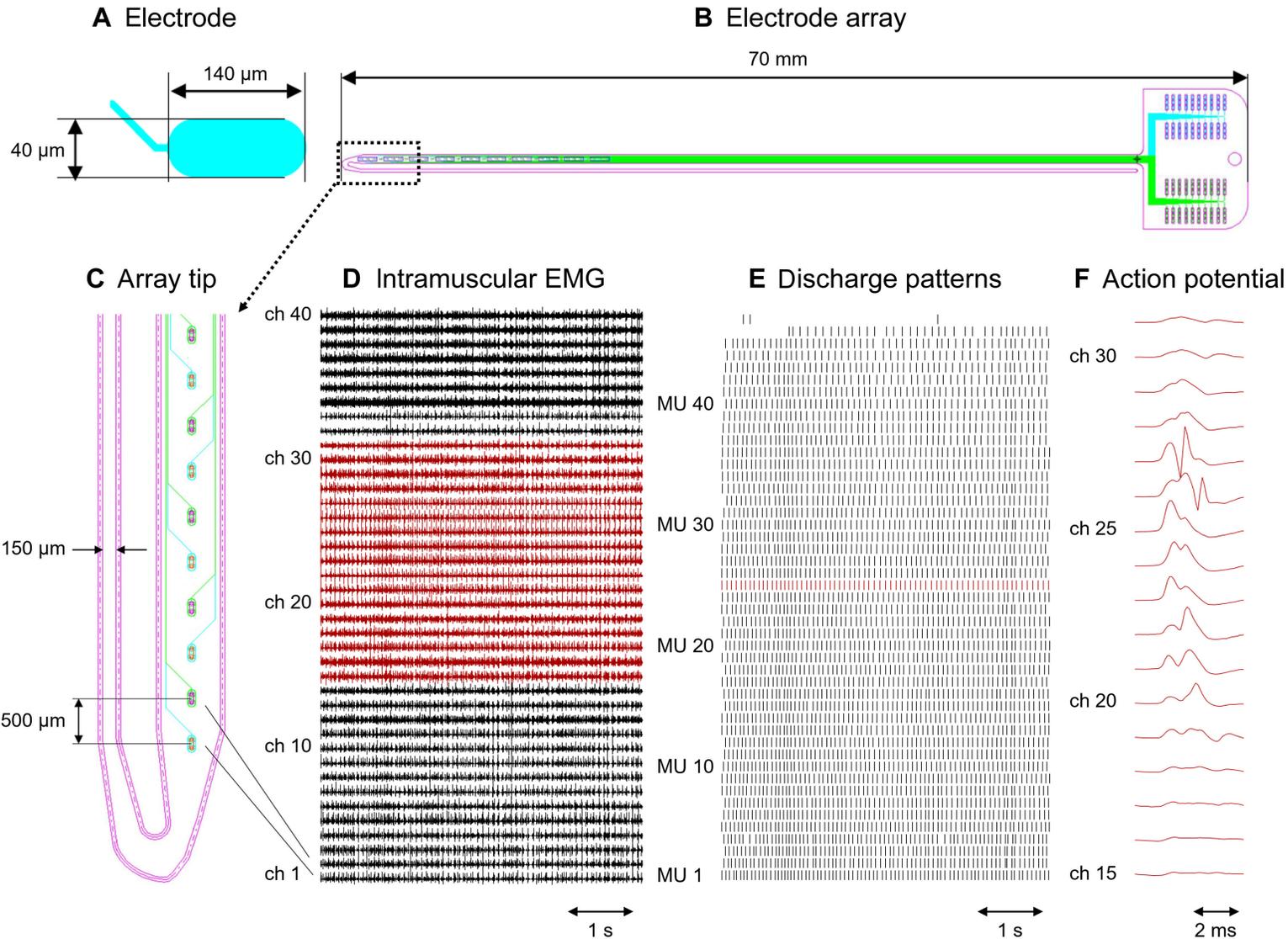
Arrays of intramuscular electrodes (Kilosort) Pachitariu et al. (2023) BioRxiv

<https://github.com/JonathanAMichaels/PixelProcessingPipeline>

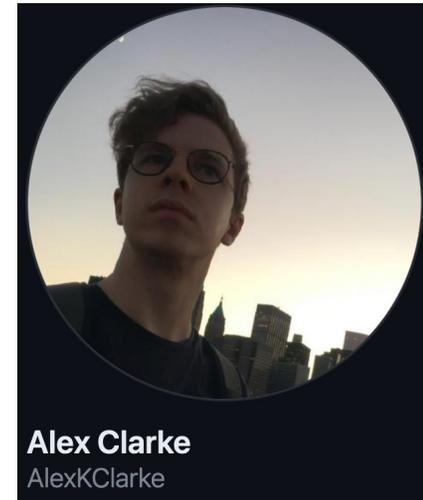


Chung et al. (2023) Elife

# EMG DECOMPOSITION USING BLIND-SOURCE SEPARATION



Muceli et al. (2022) Sci Adv



<https://github.com/AlexKClarke>  
<https://github.com/AgneGris>



# EMG DECOMPOSITION USING BLIND-SOURCE SEPARATION

**Aleš Holobar**

Holobar & Zazula (2007) IEEE  
Trans Signal Process

Farina & Holobar (2016) Proceedings of  
IEEE

Holobar & Farina (2021) IEEE  
Signal Processing Magazine

<https://isek.org/isek-jek-tutorials/>

PAPER

Multi-channel intramuscular and surface EMG decomposition  
by convolutive blind source separation

Francesco Negro<sup>1</sup> , Silvia Muceli<sup>1</sup>, Anna Margherita Castronovo<sup>1</sup>, Ales Holobar<sup>2</sup> and Dario Farina<sup>1</sup>

Published 29 February 2016 • © 2016 IOP Publishing Ltd

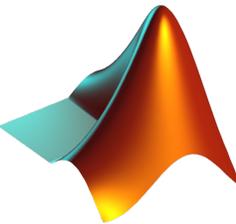
[Journal of Neural Engineering](#), [Volume 13](#), [Number 2](#)

Citation Francesco Negro *et al* 2016 *J. Neural Eng.* 13 026027

Jiang et al. (2021) IEEE Trans Neural Syst Rehabil Eng  
<https://physionet.org/content/hd-semg/1.0.0/>

Shirazi, S.Y. (2022) Github  
<https://github.com/neuromechanist/hdEMG-Decomposition>

Formento et al. (2021) J Neural Eng  
<https://github.com/carmenalab/emgdecomp>



# EMG DECOMPOSITION USING BLIND-SOURCE SEPARATION



**Simon AVRILLON**  
simonavrillon

Popular repositories [Customize your pins](#)

**MUedit** Public

App to decompose electromyographic signals and manually edit the motor unit pulse trains

MATLAB ☆ 12 🗨️ 2

**MUdictionary** Public

This repository provide access to code and data used in 'The decoding of extensive samples of motor units in human muscles reveals the rate coding of whole motoneuron pools.'

MATLAB

**I-Spin** Public

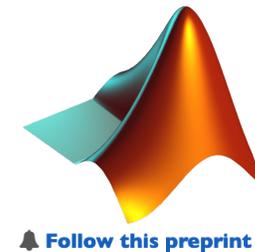
Matlab interface to identify motor unit spiking activity in real-time and display biofeedbacks based on this activity.

MATLAB ☆ 6 🗨️ 2



**Ciara Gibbs**  
ciaragibbs

<https://github.com/simonavrillon>  
<https://github.com/ciaragibbs>



New Results

 [Follow this preprint](#)

## Tutorial on MUedit: An open-source software for identifying and analysing the discharge timing of motor units from electromyographic signals

 Simon Avrillon,  François Hug, Ciara Gibbs, Dario Farina

doi: <https://doi.org/10.1101/2023.07.13.548568>

This article is a preprint and has not been certified by peer review [what does this mean?].

 0  0  0  0  0  0  53

**Abstract**

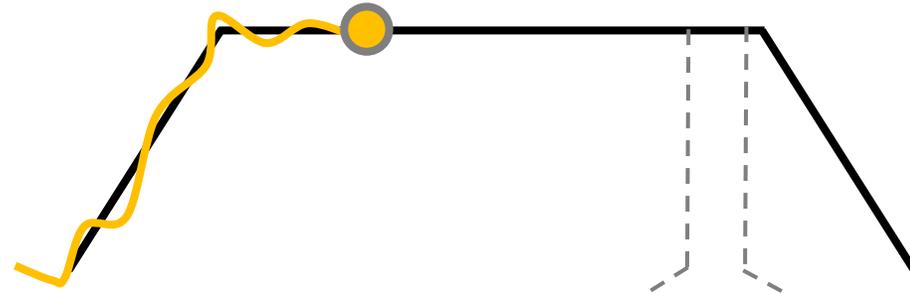
Full Text

Info/History

Metrics

 [Preview PDF](#)

# EXPERIMENTAL SETUP



Ch 1



Ch 2



Ch 3



Ch x



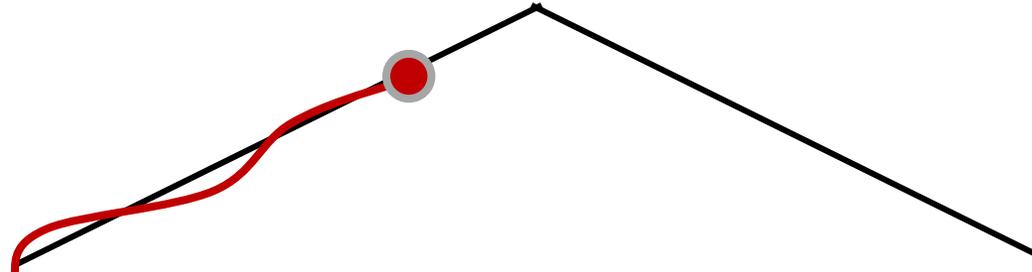
1 s

15

## Trapezoidal contraction



## Triangular contraction



# MUedit

## Decomposition panel

## Edition panel

The image displays the MATLAB App interface for MUedit, split into two panels: Decomposition and Edition.

**Decomposition panel (left):** This panel is titled "Decomposition Settings" and contains various configuration options. At the top, there are tabs for "Decomposition", "Edition", and "Visualisation". The "Decomposition Settings" section includes fields for "File name" (with a "Select file" button), "Reference" (set to "Force"), "Check EMG" (set to "Yes"), "Contrast function" (set to "logcosh"), "Initialization" (set to "EMG max"), "CoV filter" (set to "No"), "Peeloff" (set to "No"), and "Refine MUs" (set to "No"). Below these are several numerical input fields: "Number of iterations" (150), "Number of windows" (1), "Number of electrodes" (64), "Threshold target" (0.9), "Nb of extended channels" (1000), "Duplicate threshold" (0.3), "SIL threshold" (0.9), and "COV threshold" (0.5). A "Start" button is located at the bottom left.

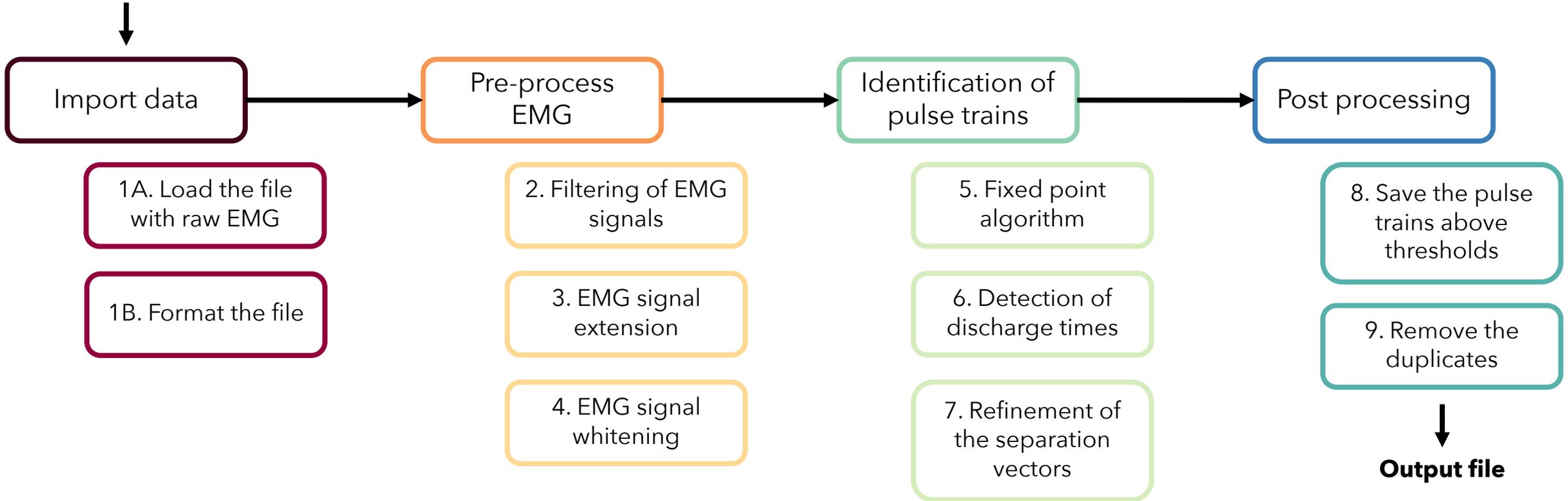
**Edition panel (right):** This panel is titled "Manual edition" and contains options for editing the data. It features a "File name" field with a "Select file" button and an "Import data" button. Below this is a "Batch processing" section with five numbered buttons: "1 - Remove all the outliers", "2 - Reevaluate all MU filters", "3 - Remove flagged MU", "4 - Remove duplicates within grids", and "5 - Remove duplicates between grids". A "Visualisation" section includes "Plot MU spike trains" and "Plot MU firing rates" buttons. At the bottom, there is a "Save the edition" section with a "Save" button. The right side of the panel shows "MU displayed # No MUs" with a dropdown arrow, and buttons for "Flag MU for deletion", "Remove outliers", and "Undo". At the very bottom, there are navigation buttons: "< Scroll left", "Zoom in", "Zoom out", and "Scroll right >".

Annotations on the image:

- "Tabs to navigate between panels" points to the "Decomposition", "Edition", and "Visualisation" tabs at the top of the Decomposition panel.
- "Panel with the settings" points to the "Decomposition Settings" section in the Decomposition panel.
- "Window for the visualisation" points to the "Visualisation" tab in the Decomposition panel.

# FRAMEWORK FOR OFFLINE EMG DECOMPOSITION

EMG signals from all  
the grids/arrays



### Decomposition Settings

10_DF.otb+	Select file
Reference	Force
Check EMG	Yes
Contrast function	logcosh
Initialization	EMG max
CoV filter	No
Peeloff	No
Refine MUs	No
Number of iterations	150
Number of windows	1
Number of electrodes	64
Threshold target	0.9
Nb of extended channels	1000
Duplicate threshold	0.3
SIL threshold	0.9
COV threshold	0.5
Start	

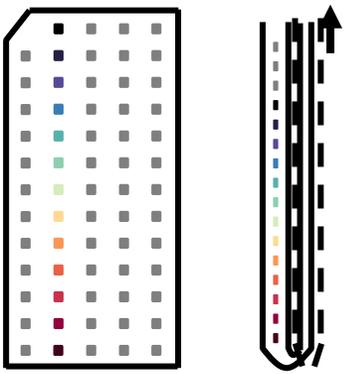
Button to import 'otb+' or 'mat' files

Options for the decomposition

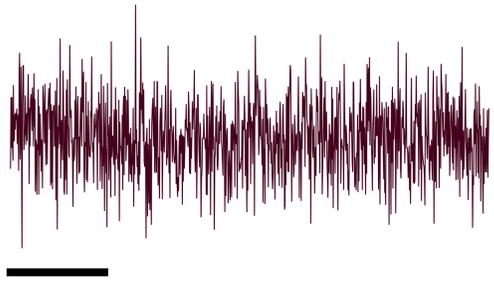
Parameters for the decomposition

Button to start the decomposition

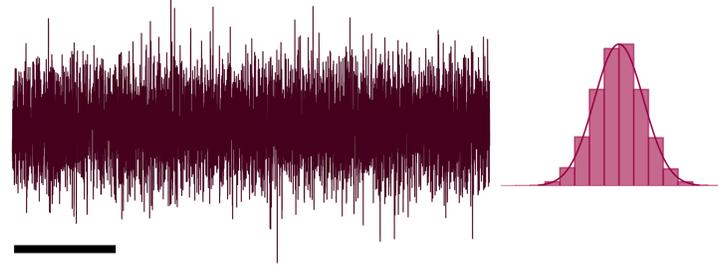
# OPTIMISATION OF SEPARATION VECTORS



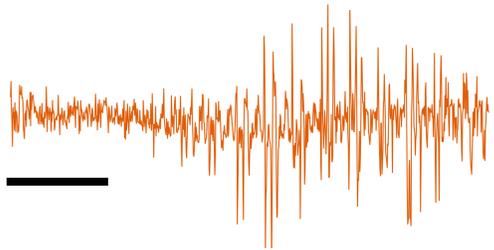
Initialisation of the separation vector



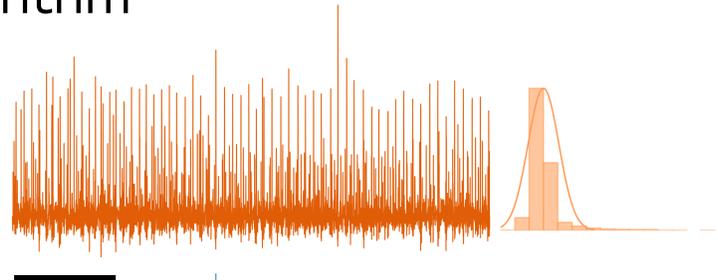
Iteration #1



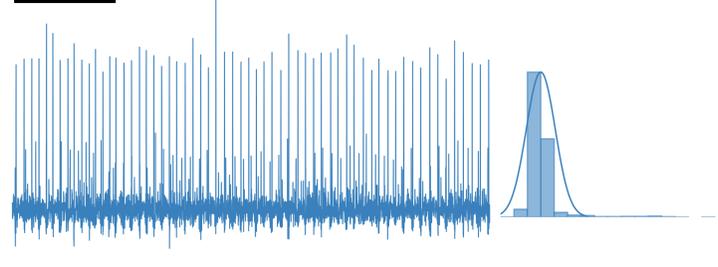
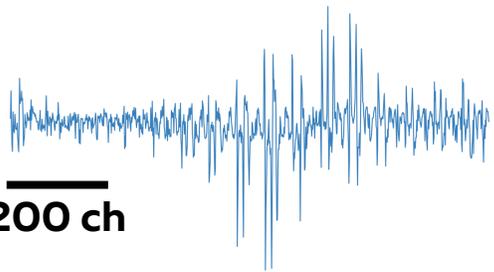
Fixed-point algorithm



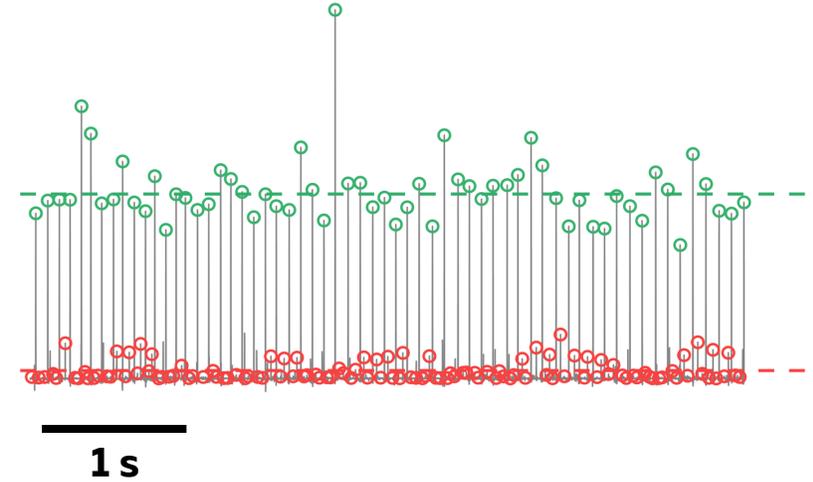
Iteration #5



Iteration #10



Spikes

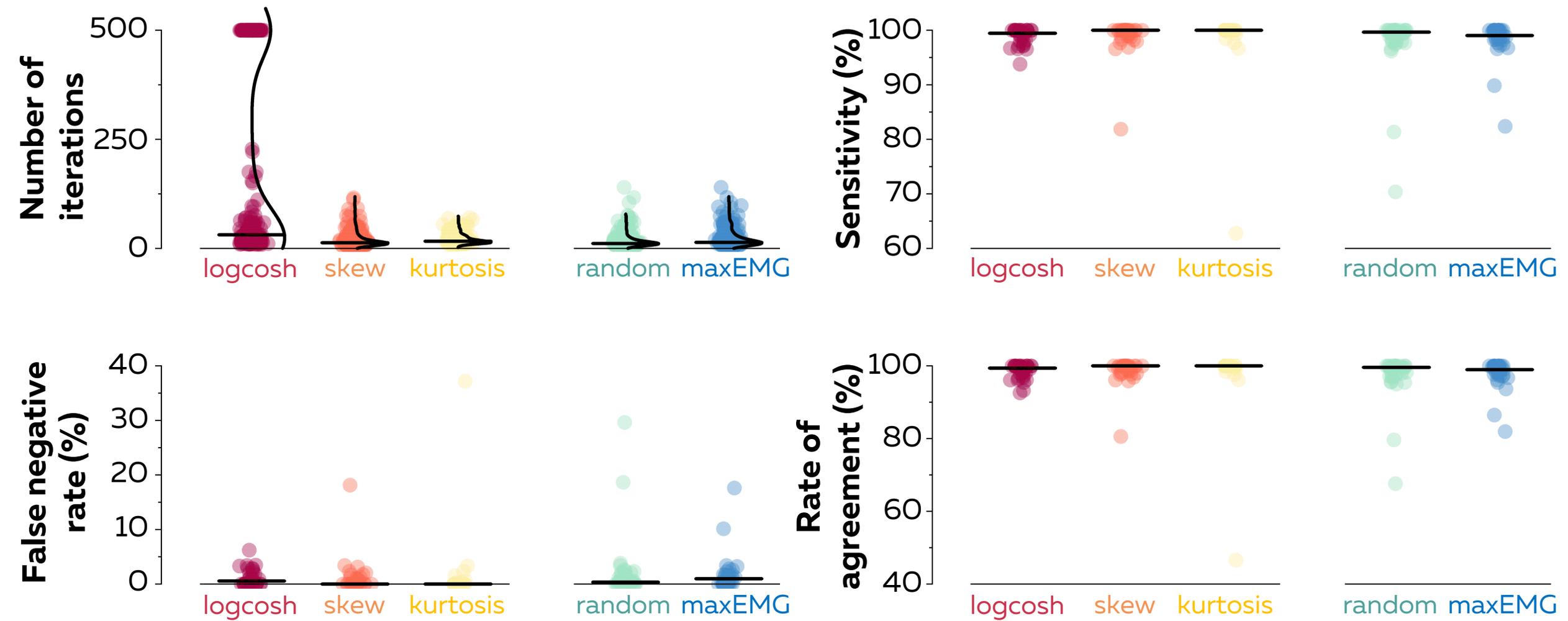


Noise

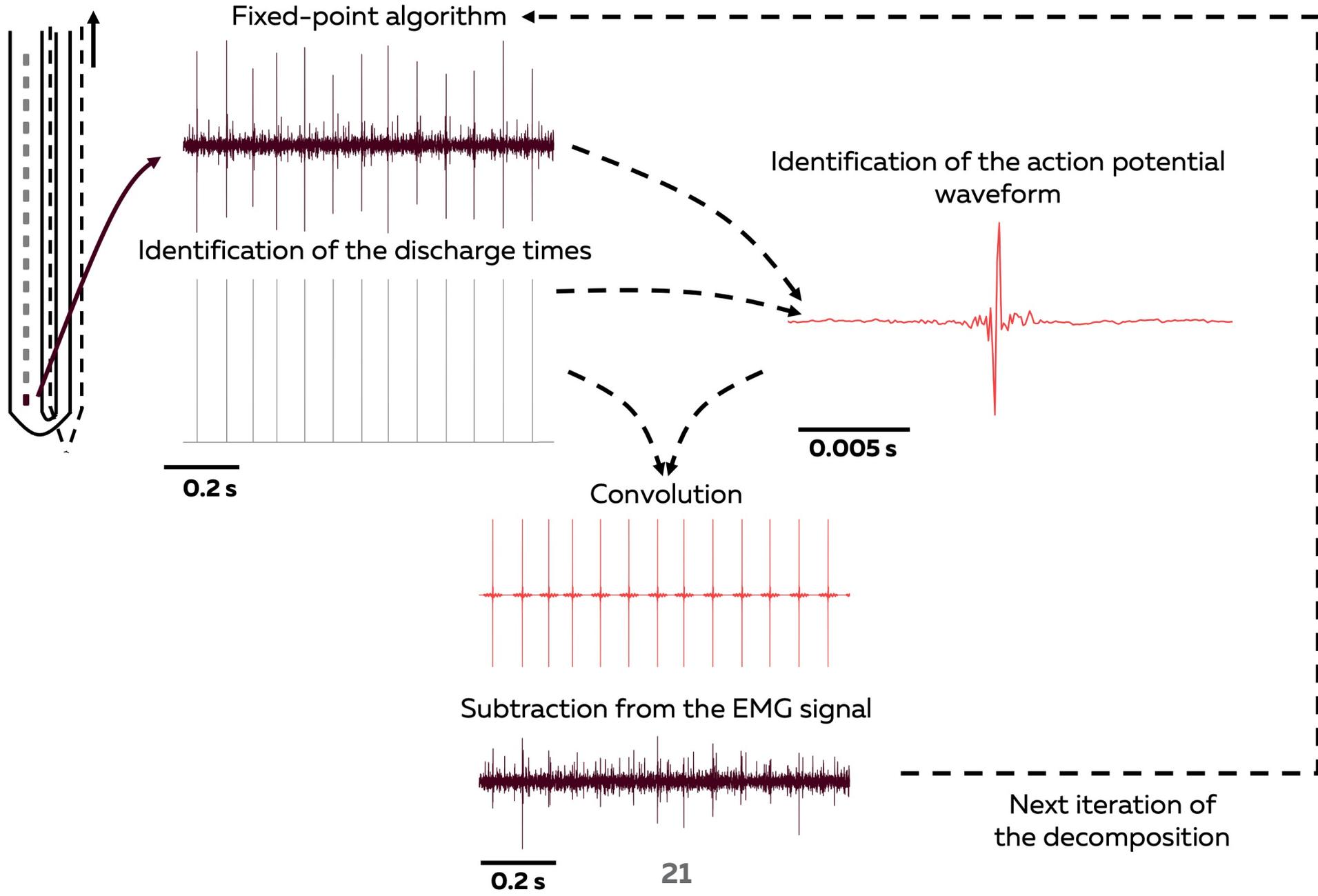
Refinement of the motor unit pulse train

Peak detection and classification

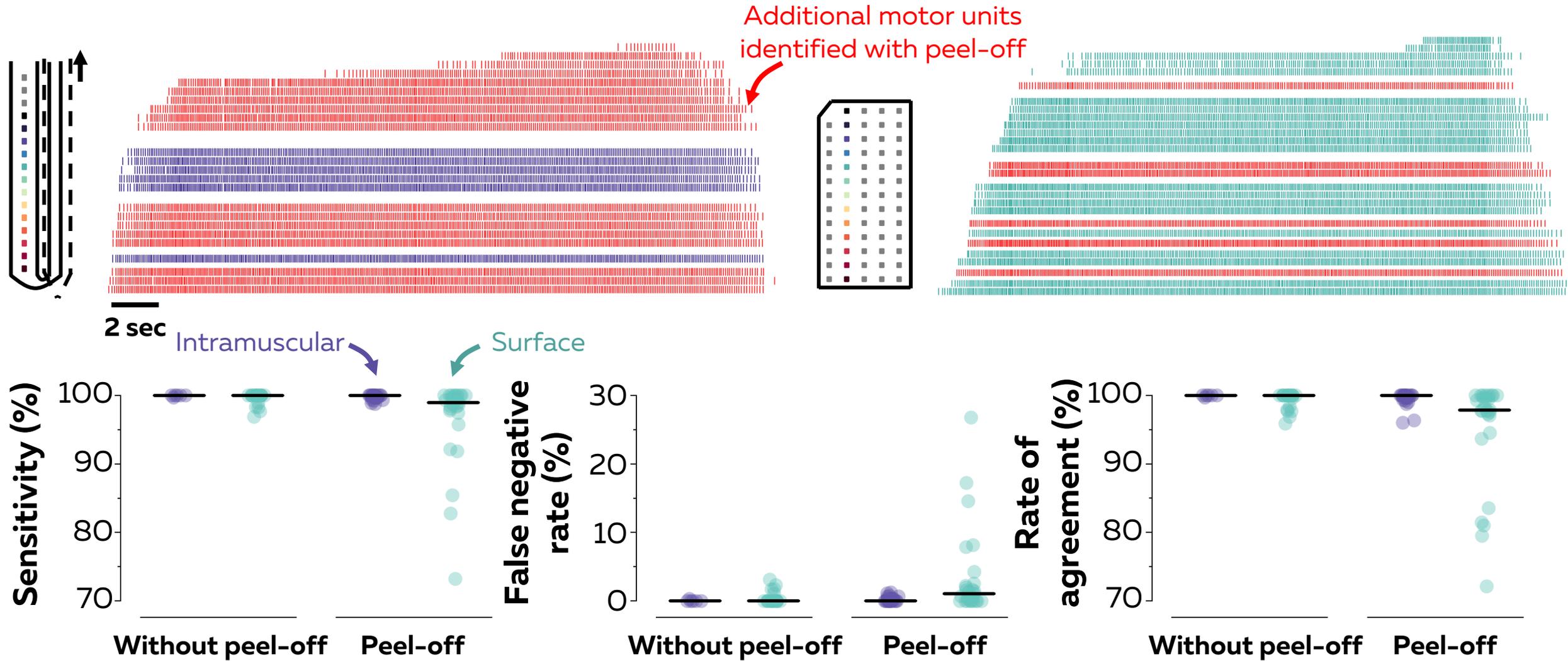
# OPTIMISATION OF SEPARATION VECTORS



# PEEL-OFF



# PEEL-OFF



List of motor units

Buttons for manual edition

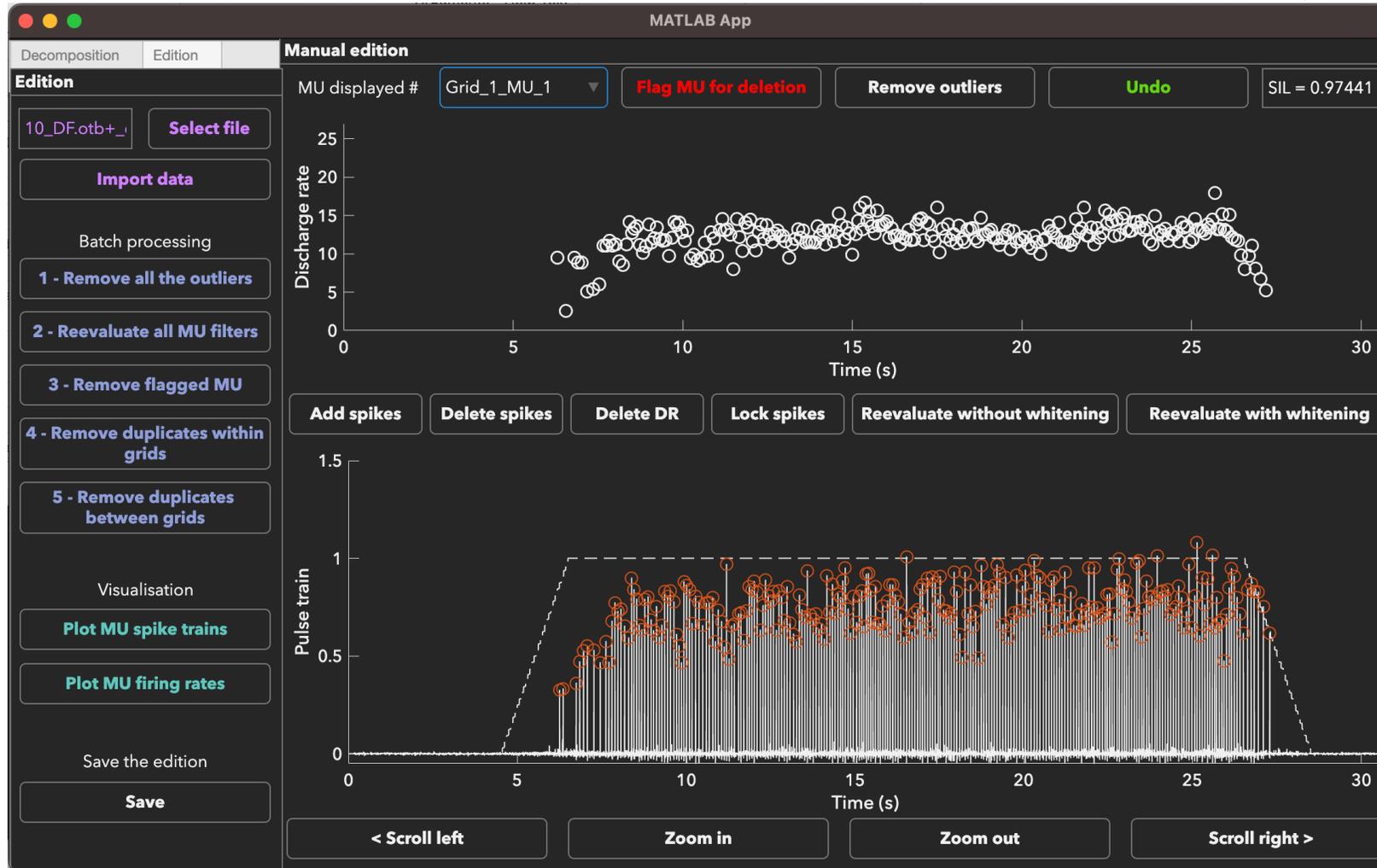
Silhouette value

Buttons to select files and import them

Panel for batch processing the manual edition

Panel for visualisation

'Save' button



Discharge rates

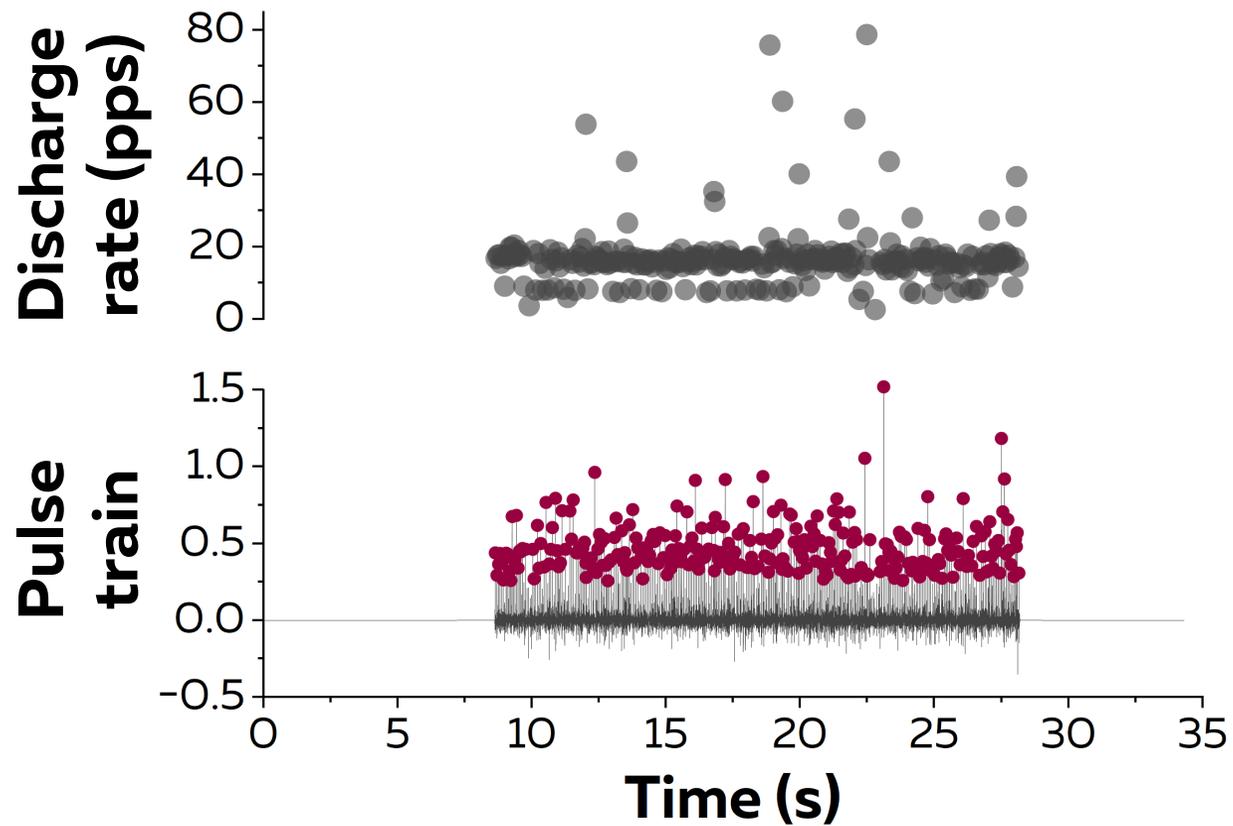
Buttons for manual edition

Motor unit pulse trains and identified spikes

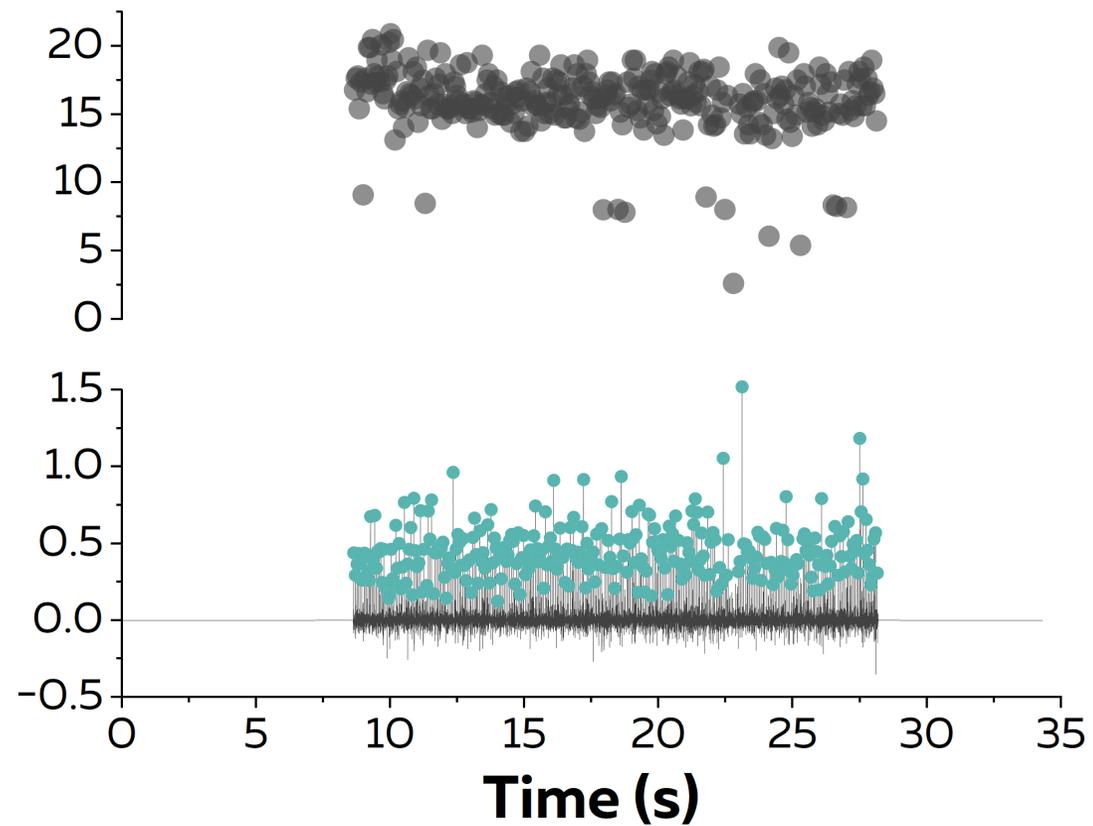
Buttons to navigate within the signal

# MANUAL EDITING

## A. Automatic decomposition

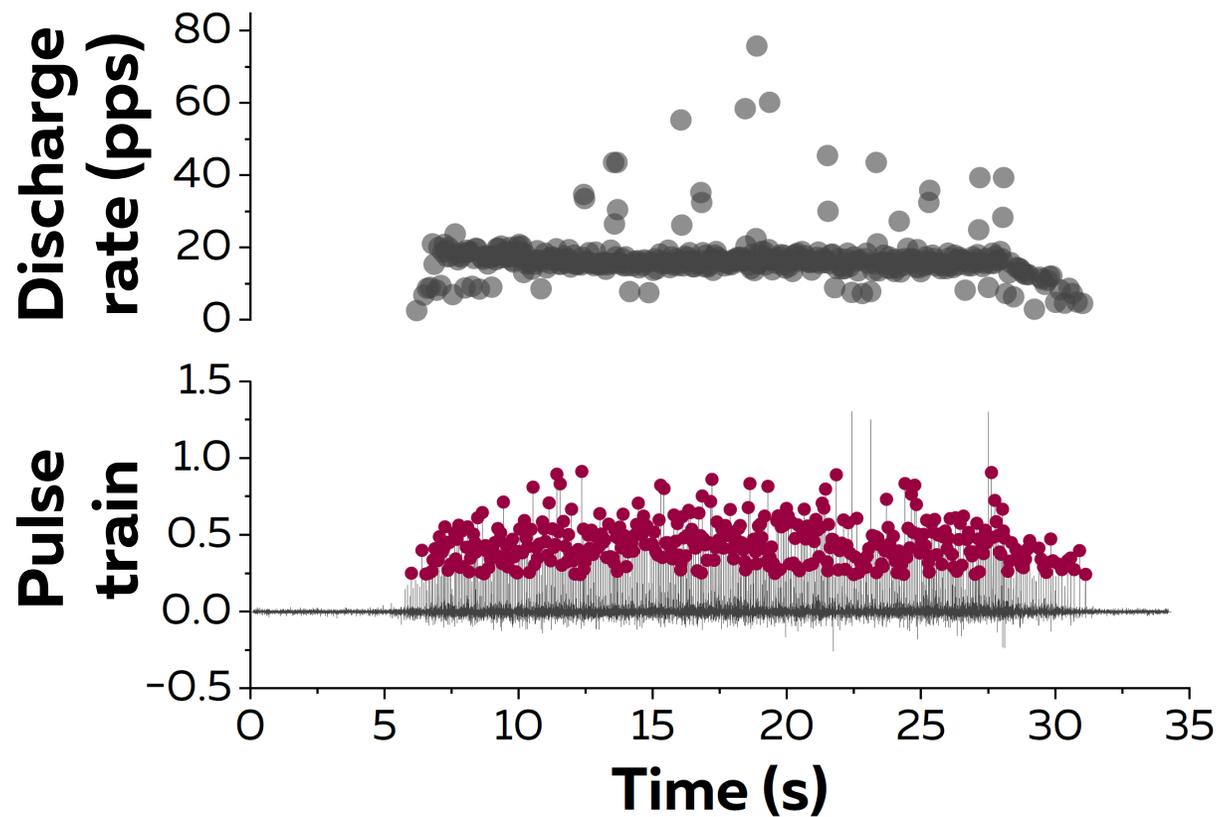


## B. Manual editing

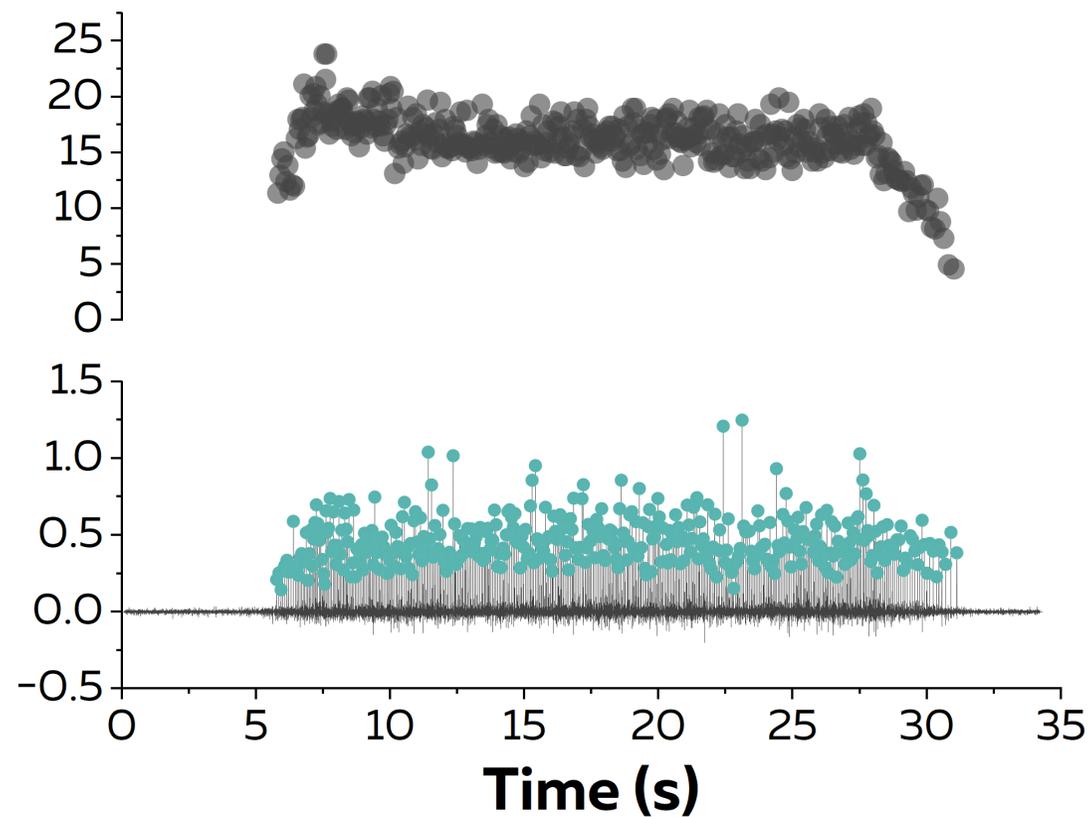


# MANUAL EDITING

**C.** Recalculation of the separation vector



**D.** Manual editing



INNOVATIONS IN EMG RECORDINGS

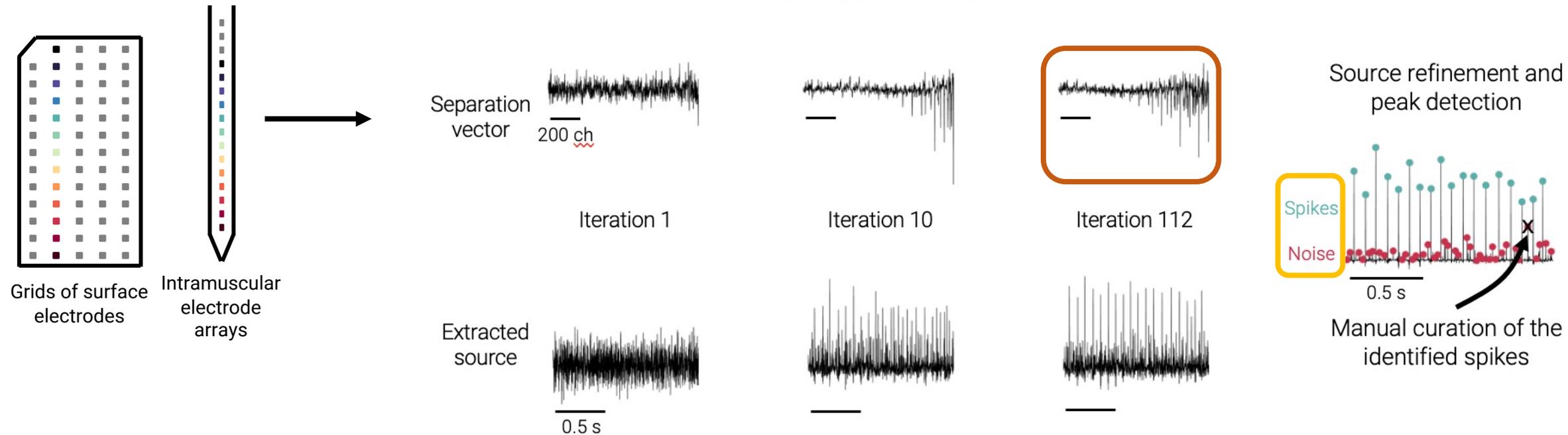
OFFLINE DECOMPOSITION

**ONLINE DECOMPOSITION**

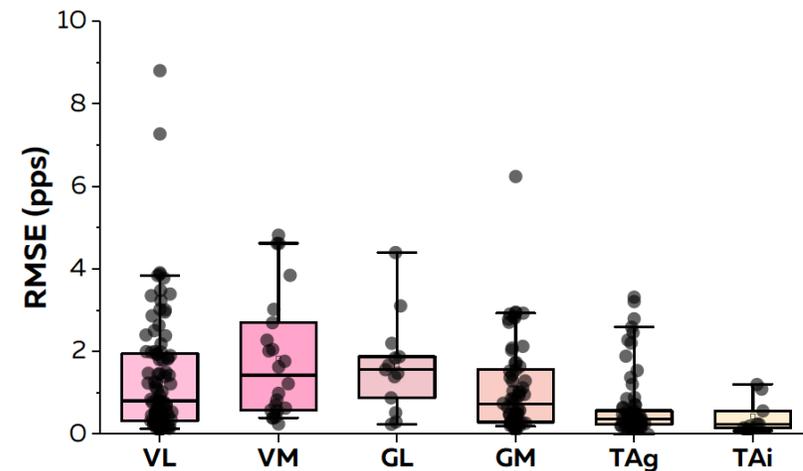
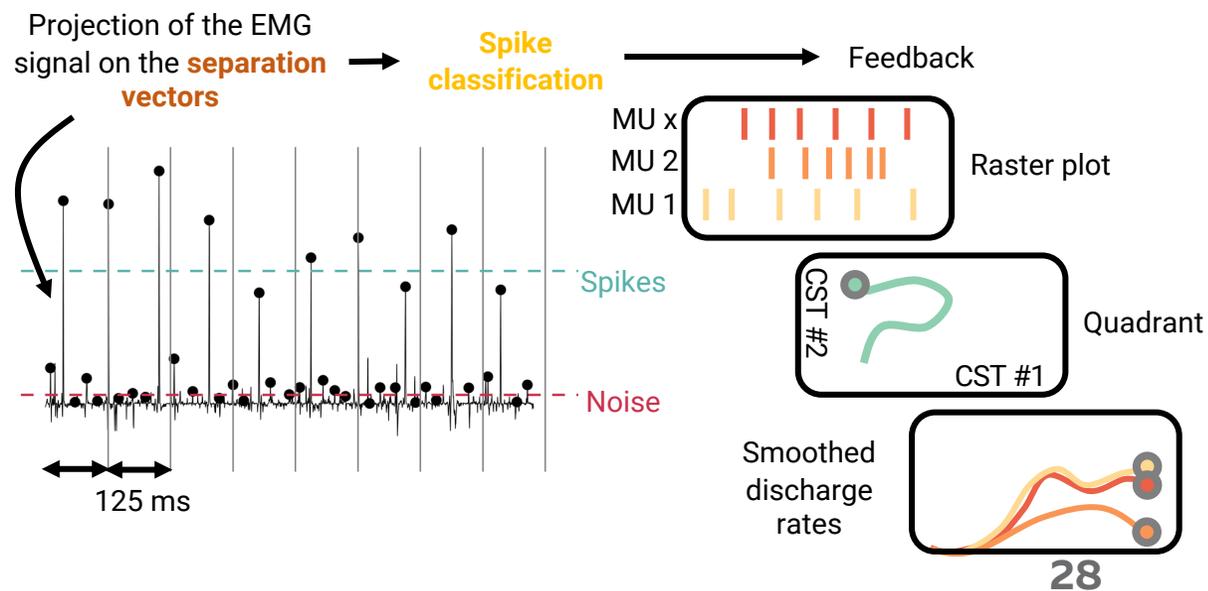


# ONLINE EMG DECOMPOSITION WITH I-SPIN LIVE

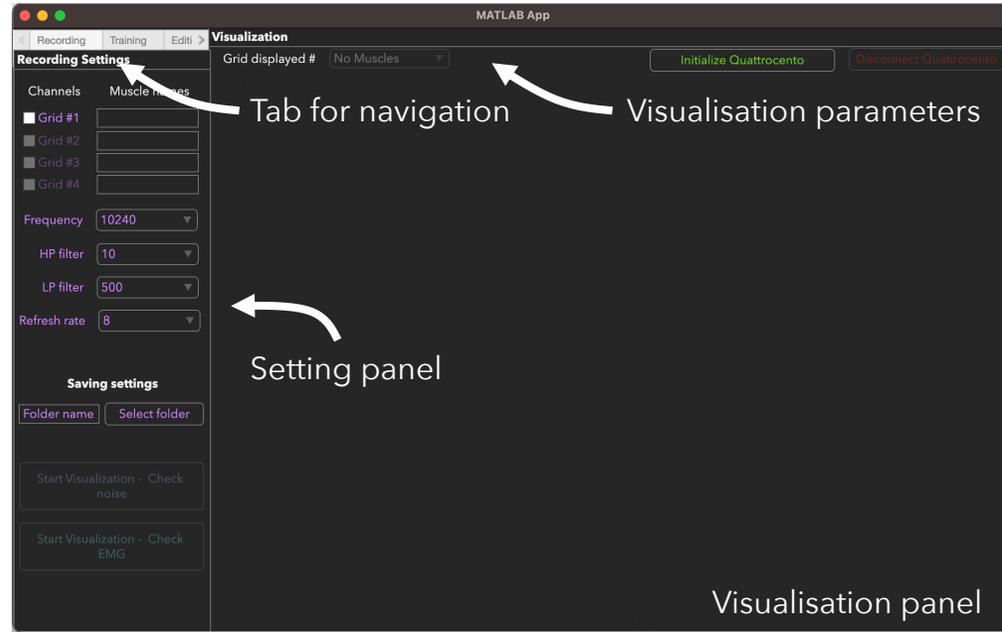
CALIBRATION



ONLINE



# 1. Recording panel



The Recording panel interface includes a 'Recording Settings' sidebar on the left with sections for 'Channels' (Grid #1-4), 'Frequency' (10240), 'HP filter' (10), 'LP filter' (500), 'Refresh rate' (8), and 'Saving settings' (Folder name, Select folder). The main area is labeled 'Visualization' and contains a 'Grid displayed #' dropdown (No Muscles), 'Initialize Quattrocento', and 'Disconnect Quattrocento' buttons. White arrows point to the 'Recording' tab, the 'Grid displayed #' dropdown, and the 'Setting panel' label.

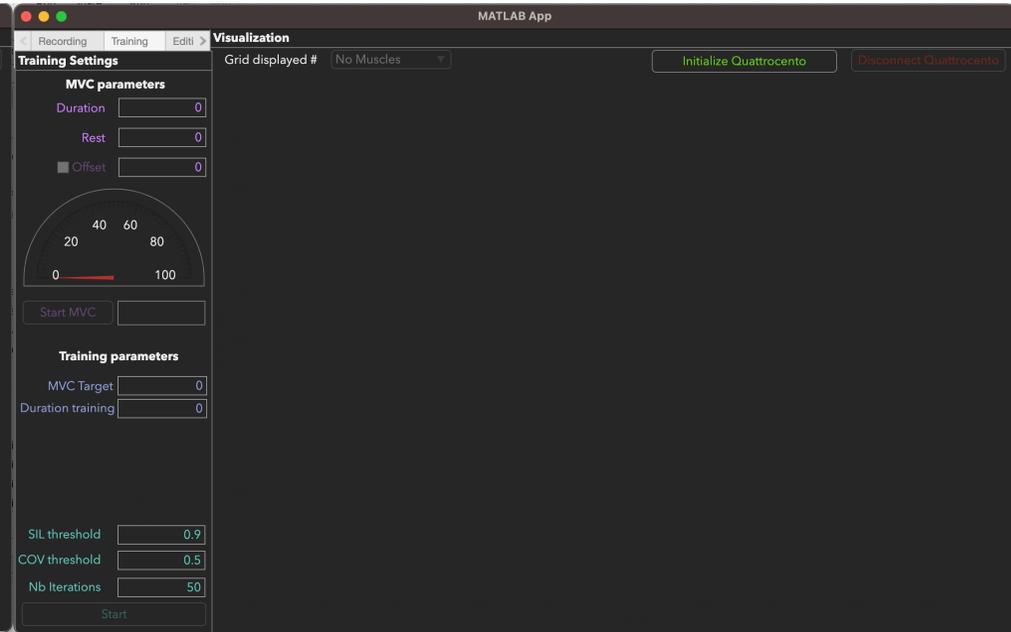
Tab for navigation

Visualisation parameters

Setting panel

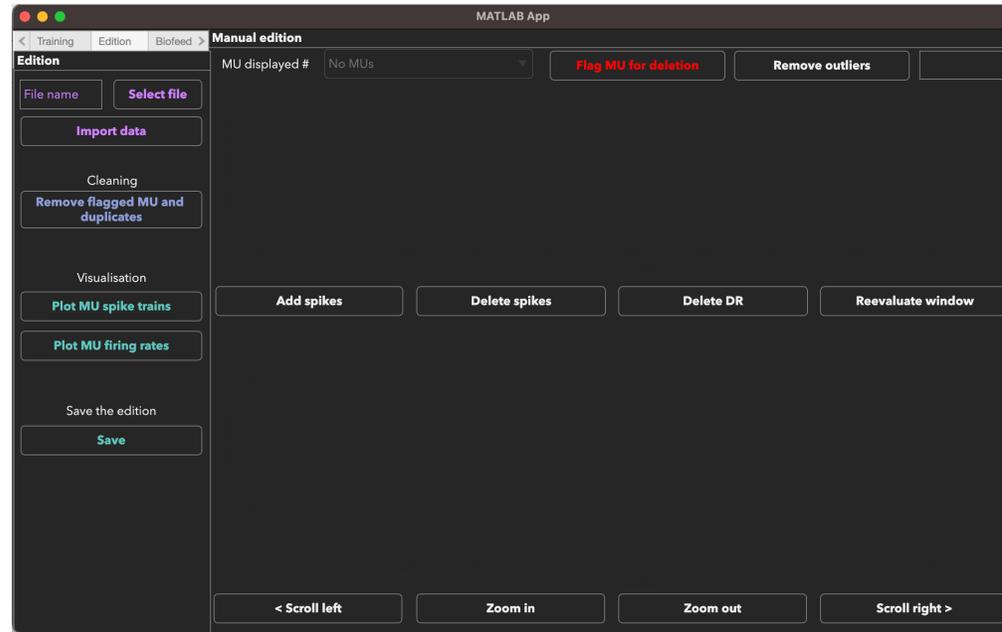
Visualisation panel

# 2. Training panel



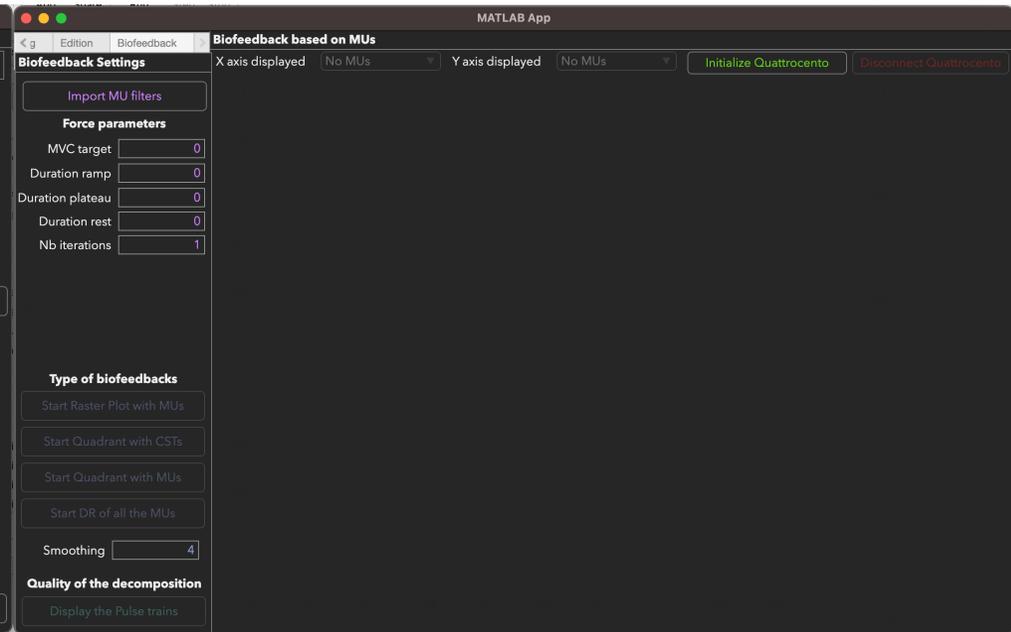
The Training panel interface features a 'Training Settings' sidebar with 'MVC parameters' (Duration, Rest, Offset) and 'Training parameters' (MVC Target, Duration training, SIL threshold, COV threshold, Nb Iterations). The main area is labeled 'Visualization' and includes a 'Grid displayed #' dropdown (No Muscles), 'Initialize Quattrocento', and 'Disconnect Quattrocento' buttons. A semi-circular progress indicator is visible between the settings and the main area.

# 3. Edition panel



The Edition panel interface has an 'Edition' sidebar with 'Import data', 'Cleaning' (Remove flagged MU and duplicates), 'Visualisation' (Plot MU spike trains, Plot MU firing rates), and 'Save the edition' (Save) sections. The main area is labeled 'Manual edition' and contains 'MU displayed #' dropdown (No MUs), 'Flag MU for deletion', and 'Remove outliers' buttons. At the bottom, there are 'Add spikes', 'Delete spikes', 'Delete DR', 'Reevaluate window', 'Scroll left', 'Zoom in', 'Zoom out', and 'Scroll right' controls.

# 4. Biofeedback panel



The Biofeedback panel interface features a 'Biofeedback Settings' sidebar with 'Force parameters' (MVC target, Duration ramp, Duration plateau, Duration rest, Nb iterations) and 'Type of biofeedbacks' (Start Raster Plot with MUs, Start Quadrant with CSTs, Start Quadrant with MUs, Start DR of all the MUs). The main area is labeled 'Biofeedback based on MUs' and includes 'X axis displayed' and 'Y axis displayed' dropdowns (No MUs), 'Initialize Quattrocento', and 'Disconnect Quattrocento' buttons. A 'Smoothing' input field is also present.

# INPUTS

EMG signals from all the grids

1

Recording panel

1. Check the baseline noise

2. Identify the noisy channels

A mask for all the grids

**A file with the raw EMG**

EMG signals from all the grids  
Force

2

Training panel

1. Remove force offset

2. Measure the MVC

3. Perform the baseline contraction

Separation vectors from the decomposition

Covariation matrix of the EMG signals for each grid

Centroids for spikes classification

**A file with the EMG decomposed**

**A file with the EMG decomposed**

3

Edition panel

1. Manually clean the spike trains

2. Re-evaluate the spike trains

3. Remove the flagged unreliable spike trains

**A file with the EMG decomposed and cleaned**

Force  
EMG signals from all the grids

**A file with the EMG decomposed and edited**

4

Biofeedback panel

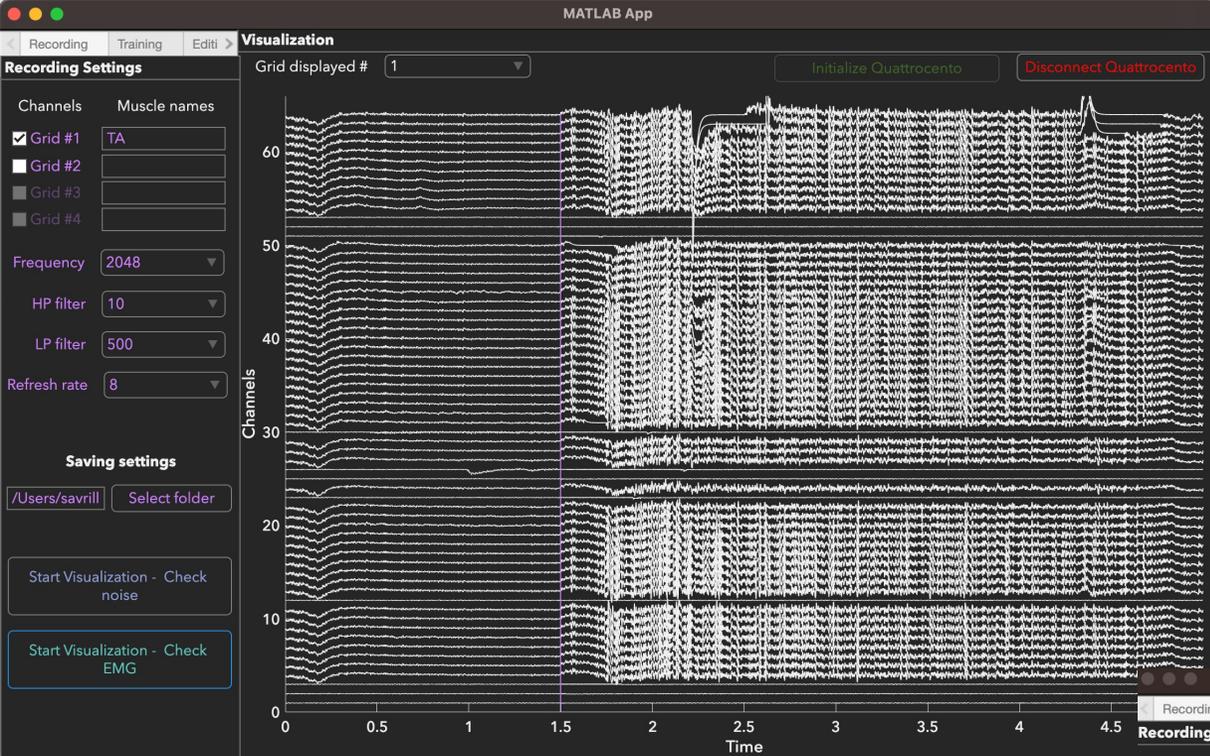
1. Load the edited file

2. Perform the online task

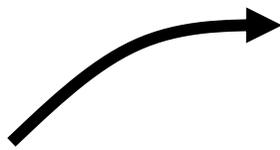
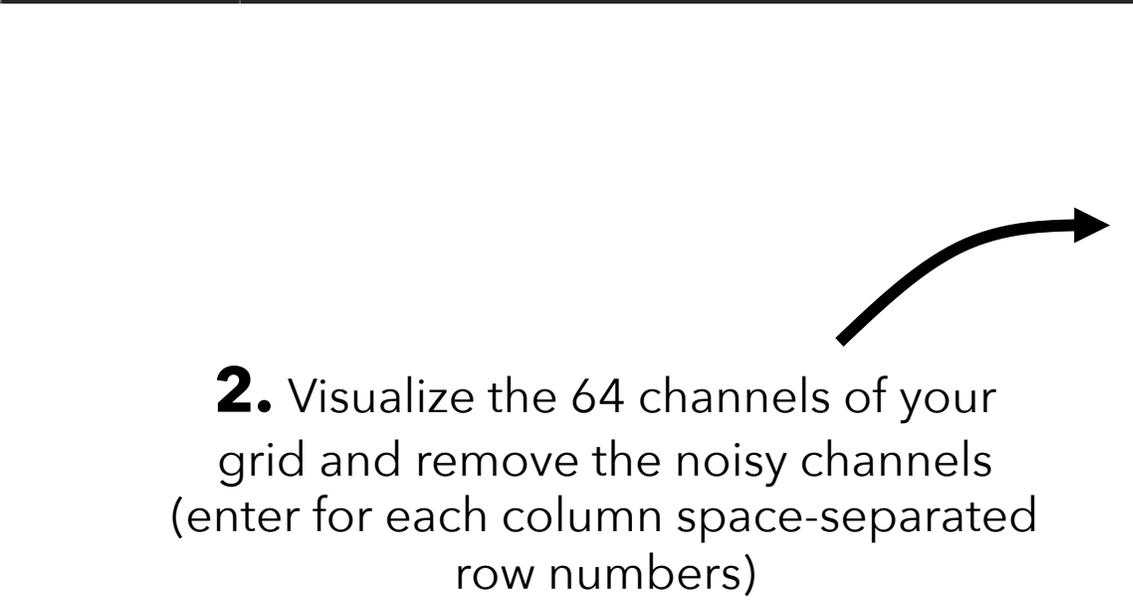
3. Visually check the quality of the decomposition

**A file with the EMG decomposed, the targets, and the raw EMG and force data**

# OUTPUTS



**1.** Visualize the 64 channels of your grid in real-time (buffer of five seconds)



**2.** Visualize the 64 channels of your grid and remove the noisy channels (enter for each column space-separated row numbers)

Select the ba...

col #1  
1 2 3 12

col #2  
10 12 13

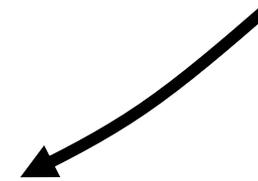
col #3  
4

col #4  
12 13

col #5  
1]

OK Cancel

**1.** Set the parameters for the maximal voluntary contractions. The participant will perform three maximal voluntary contractions



**Training Settings**

**MVC parameters**

Duration

Rest

Offset

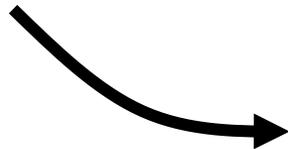
0 20 40 60 80 100

Start MVC

**2.** Check the box for recording and removing the force offset

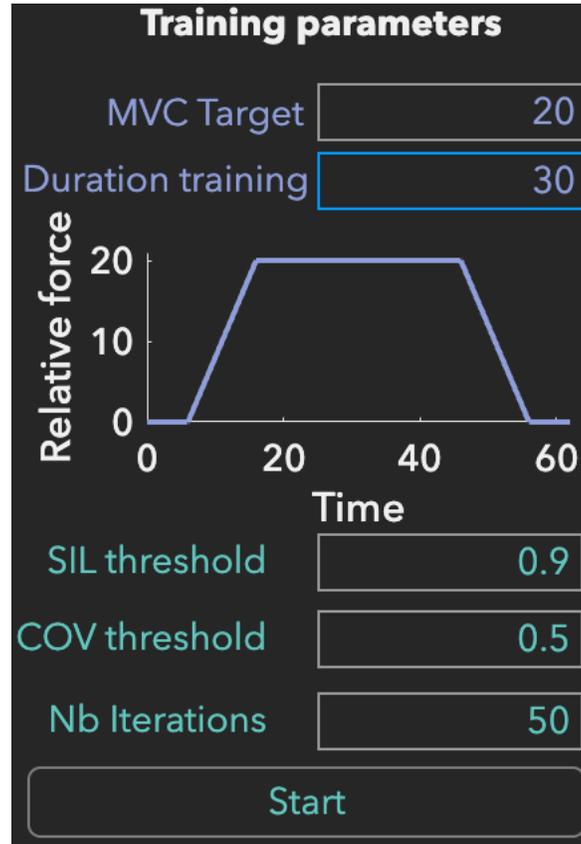


**3.** Start the MVC. The button turns green when the participant must perform the MVC



## 2. Set the parameters for the decomposition

- The SIL threshold enables you to remove the spike trains with a short distance between the spikes and the noise
- The COV threshold enables you to remove the spike trains with a high variability between interspike intervals
- The number of iterations enables you to potentially increase the number of identified motor units

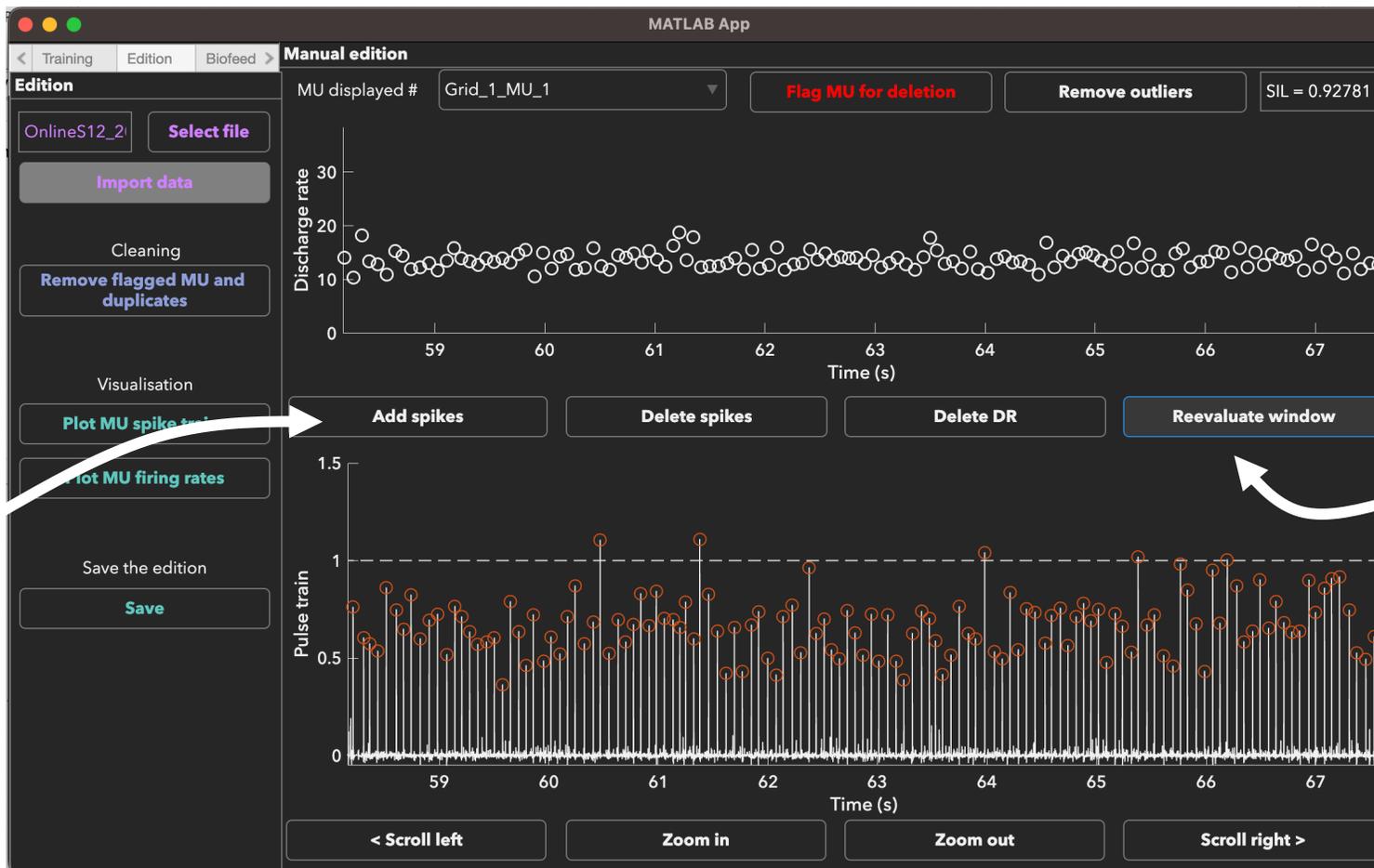


1. Set the parameters for the baseline contraction. The target is automatically updated.

**1.** Find the decomposition file and import it



**3.** Manually add missing spikes or remove falsely identified artifacts



**2.** Remove the outliers  
(low spikes associated with discharge rates above the averaged discharge rate + 3 standard deviations)

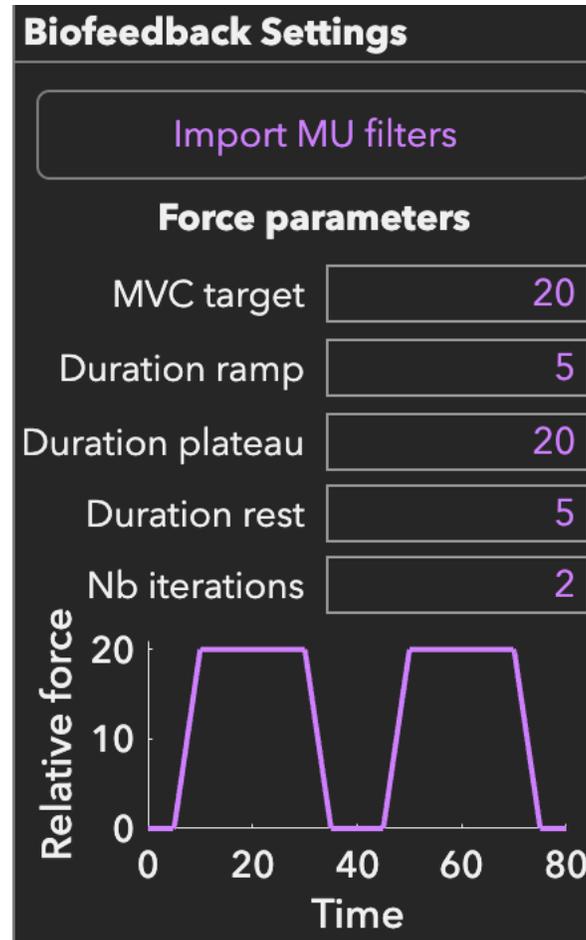


**4.** Reevaluate the spike trains

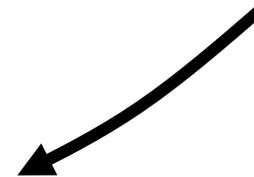


**5.** If the spike train is unreliable, flag the motor unit

1. Import the edited motor unit spike trains to update the decomposition parameters



2. Set the parameters for the online contractions. The target is automatically updated.



# Case scenarios

1. Select the type of visual feedback you want to provide

**Type of biofeedbacks**

- Start Raster Plot with MUs
- Start Quadrant with CSTs
- Start Quadrant with MUs
- Start DR of all the MUs

Smoothing

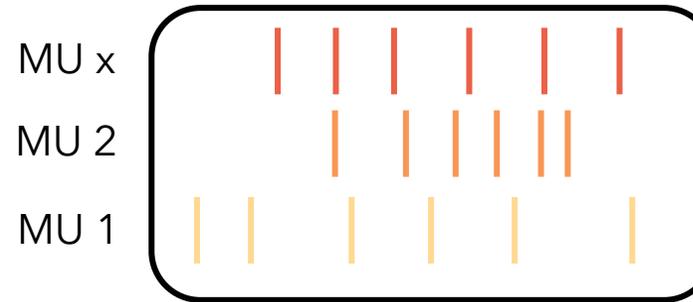
**Quality of the decomposition**

- Display the Pulse trains

2. Select the index of smoothing (i.e., number of windows to average)

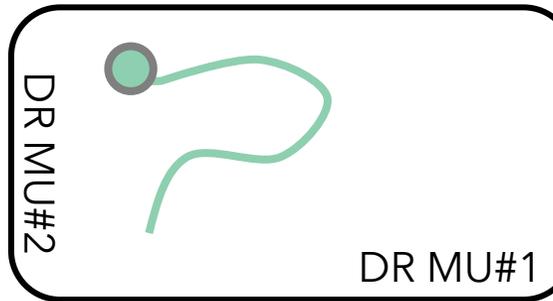
3. At the end of each contraction, visually check the quality of the motor unit spike trains

Raster plot



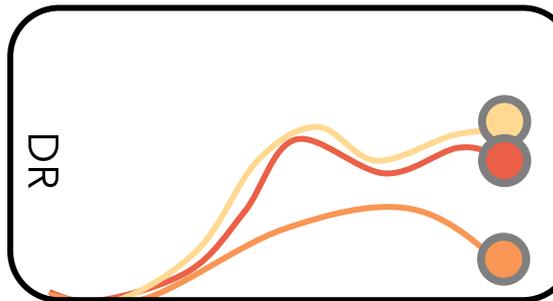
You identify all the motor units from the grid #1, e.g., the TA, and display the discharge times to the participant

Quadrant



You identify one motor unit from the grid #1 and one motor unit from the grid #2. The cursor move according to their individual discharge rate

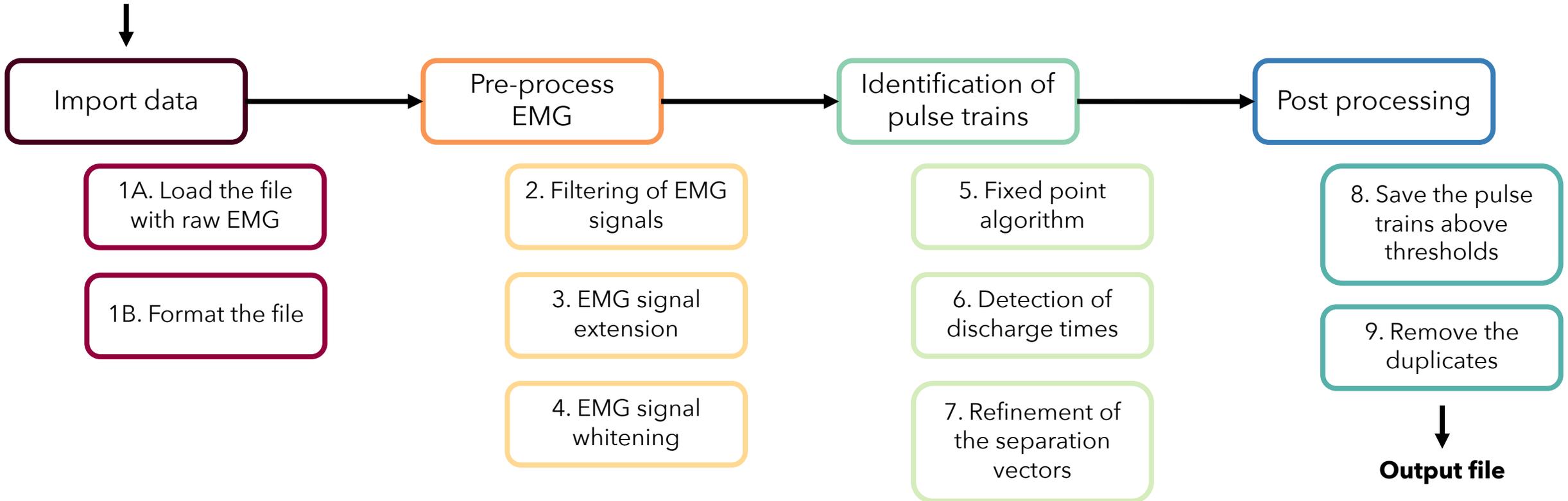
Smoothed discharge rates



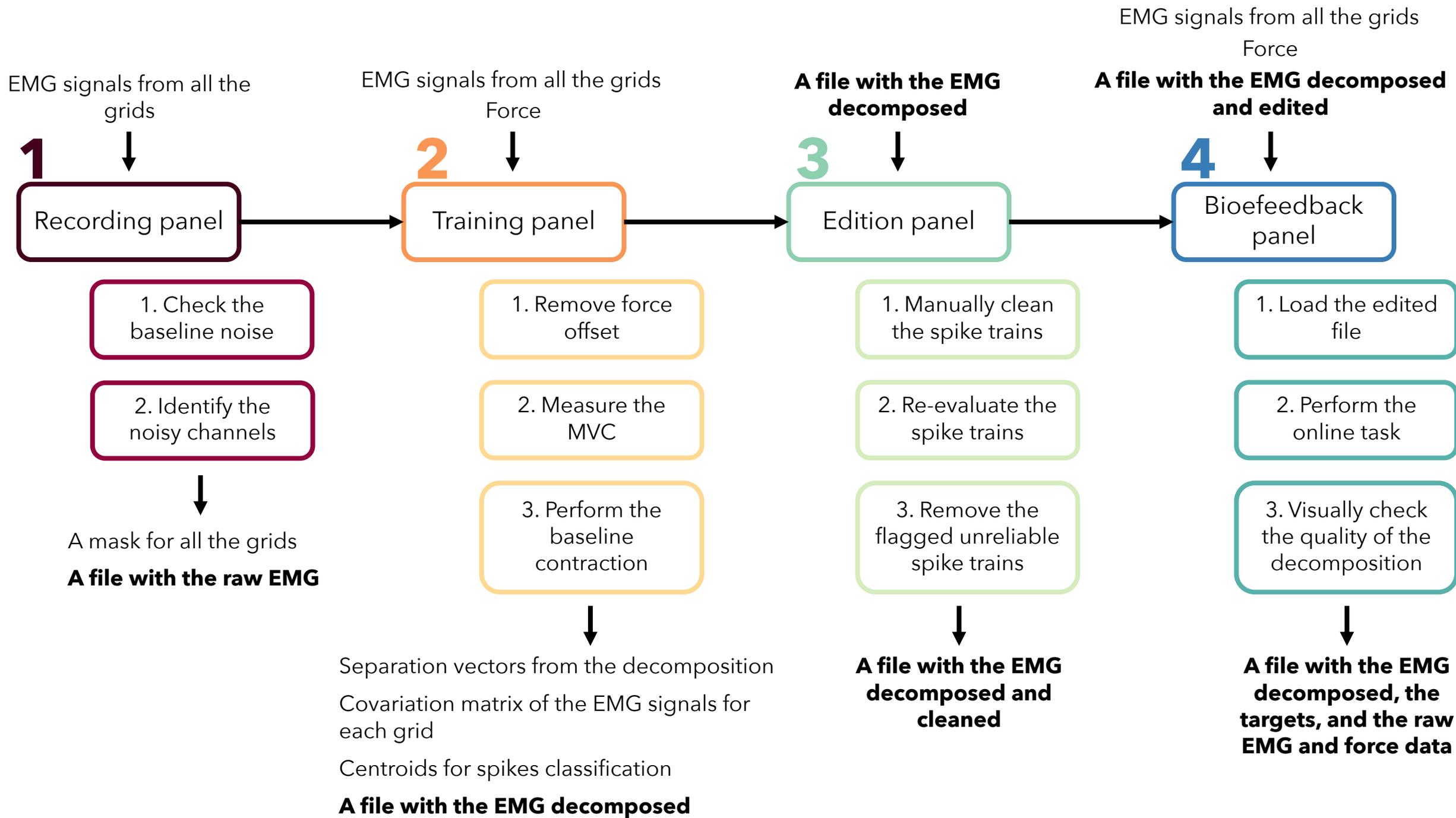
You identify all the motor units from the grid #2, i.e., the VL, and display their smoothed discharge rates to the participant

# FRAMEWORK FOR OFFLINE EMG DECOMPOSITION

EMG signals from all  
the grids/arrays



# INPUTS



# OUTPUTS

# THANK YOU

Simon  
Avrillon



Dario  
Farina



François  
Hug



Julien Rossato, Foundation Santa Lucia, Italy  
Ciara Gibbs, Imperial College London, UK  
Arnault Caillet, Imperial College London, UK