Open-source software to decompose and edit EMG signals

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Dario Farina, Imperial College London, UK

INNOVATIONS IN EMG RECORDINGS

OFFLINE DECOMPOSITION

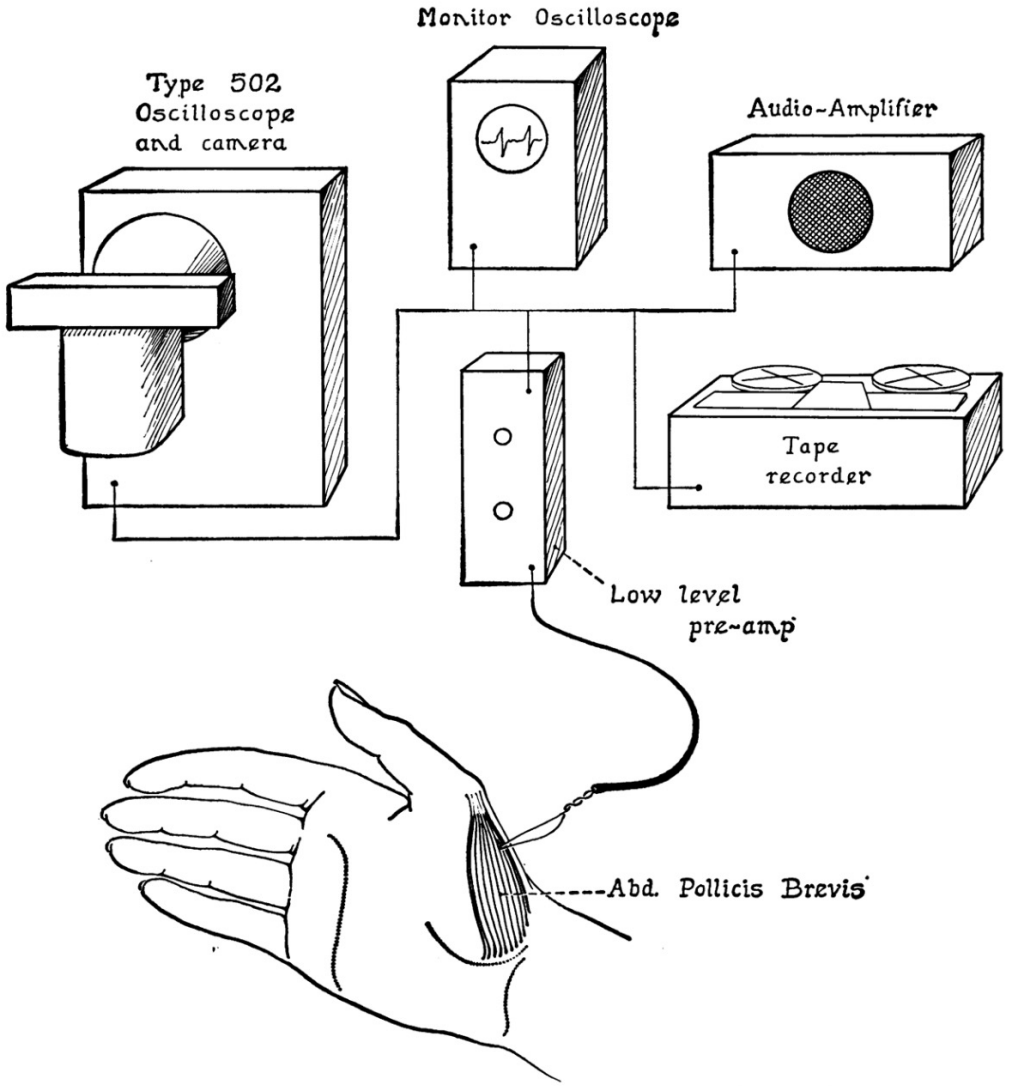
ONLINE DECOMPOSITION

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

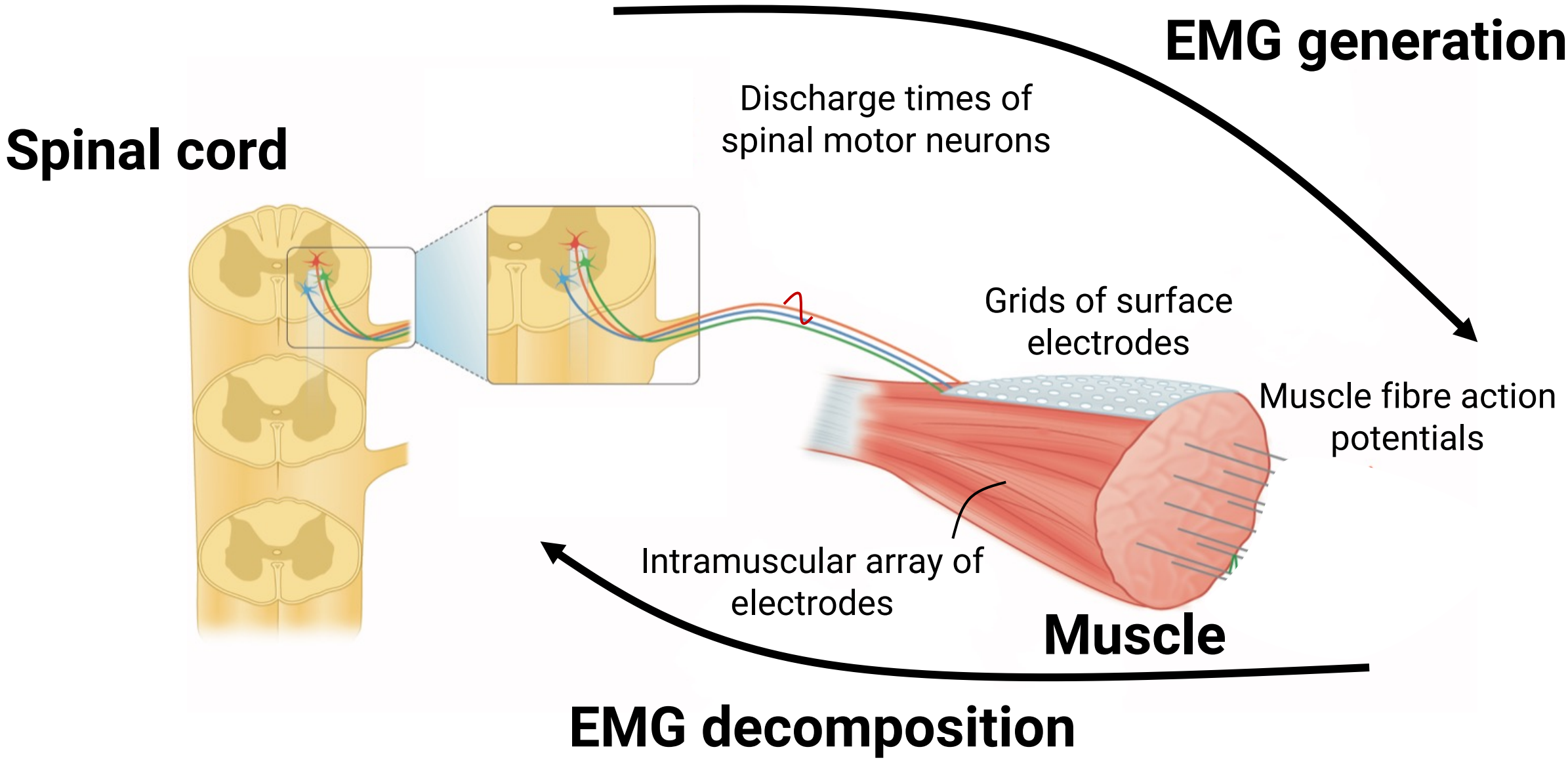
E. Formento, P. Botros*, J. M. Carmena*
University of California, Berkeley

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

Barsakcioglu et al. (2021) IEEE Trans Biomed Eng

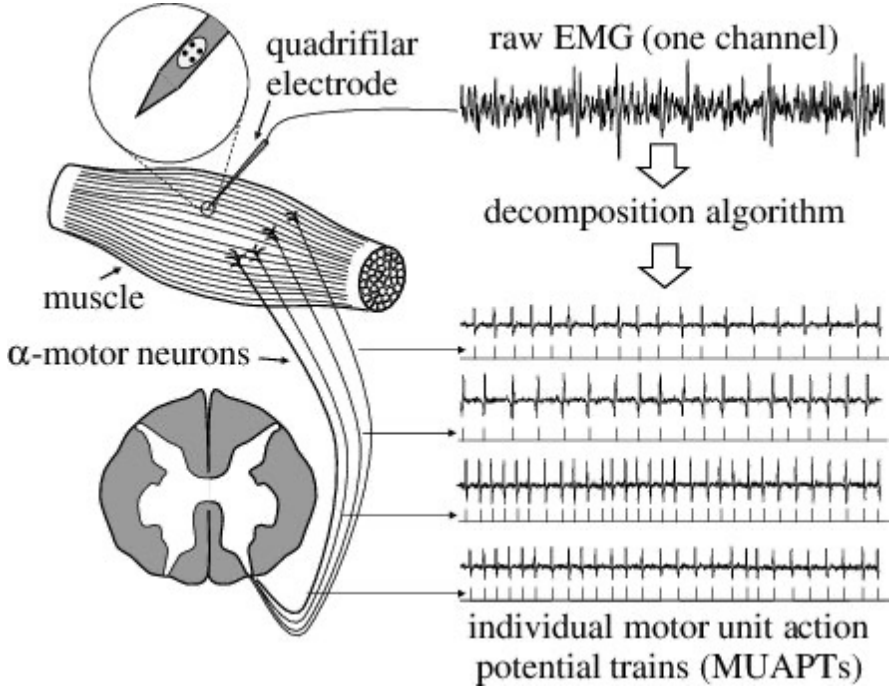
Formento et al. (2021) J Neural Eng

DECOMPOSITION OF EMG SIGNALS



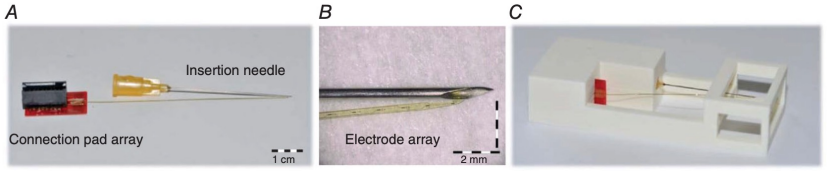
INTRODUCTION

Quadrifillar needle electrodes



De Luca & Forrest (1972) IEEE Trans Biomed Eng

Intramuscular electrodes on thin films

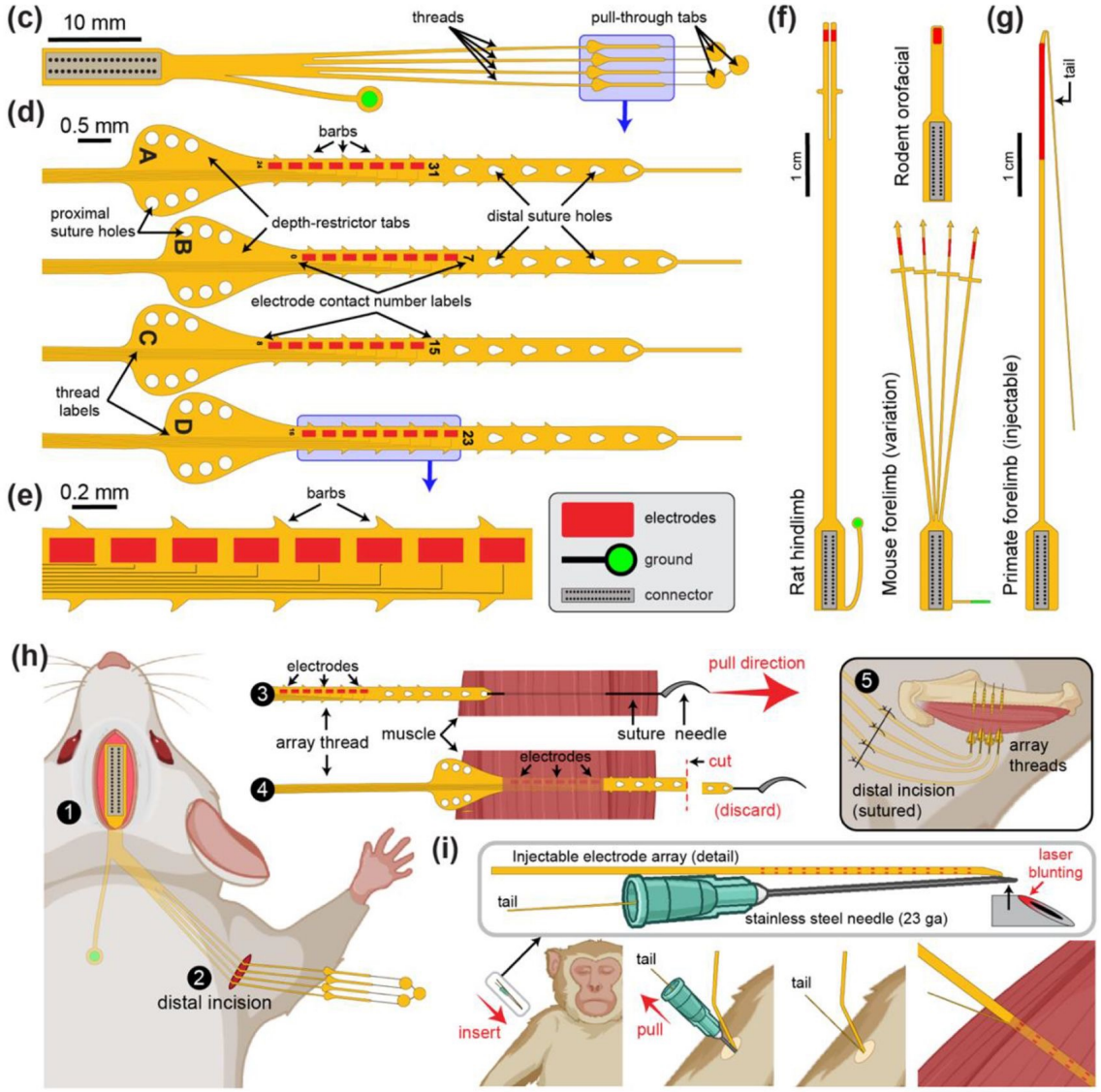


Muceli et al. (2015) J Physiol

Muceli et al. (2022) Sci Adv

Farina et al. (2008) J Neurophysiol

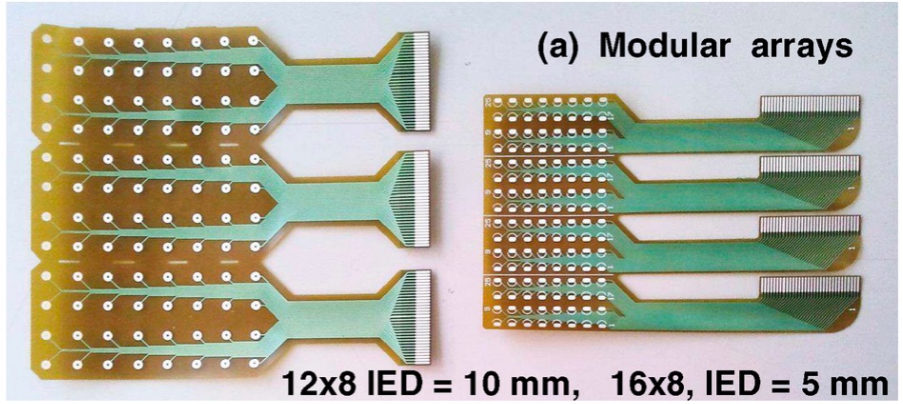
Myomatrix array



Chung et al. (2023) Elife

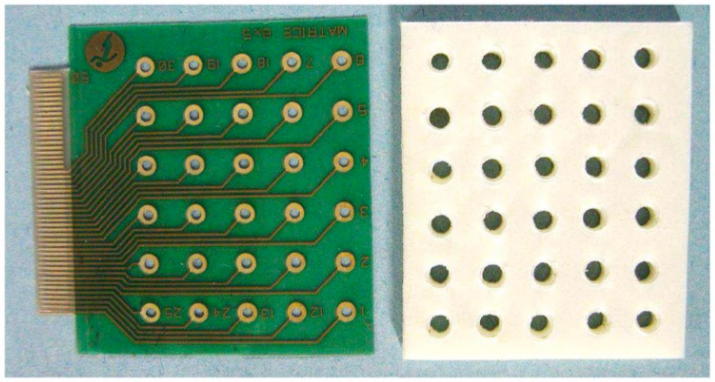
EVOLUTION OF EMG RECORDING METHODS

Arrays of surface electrodes



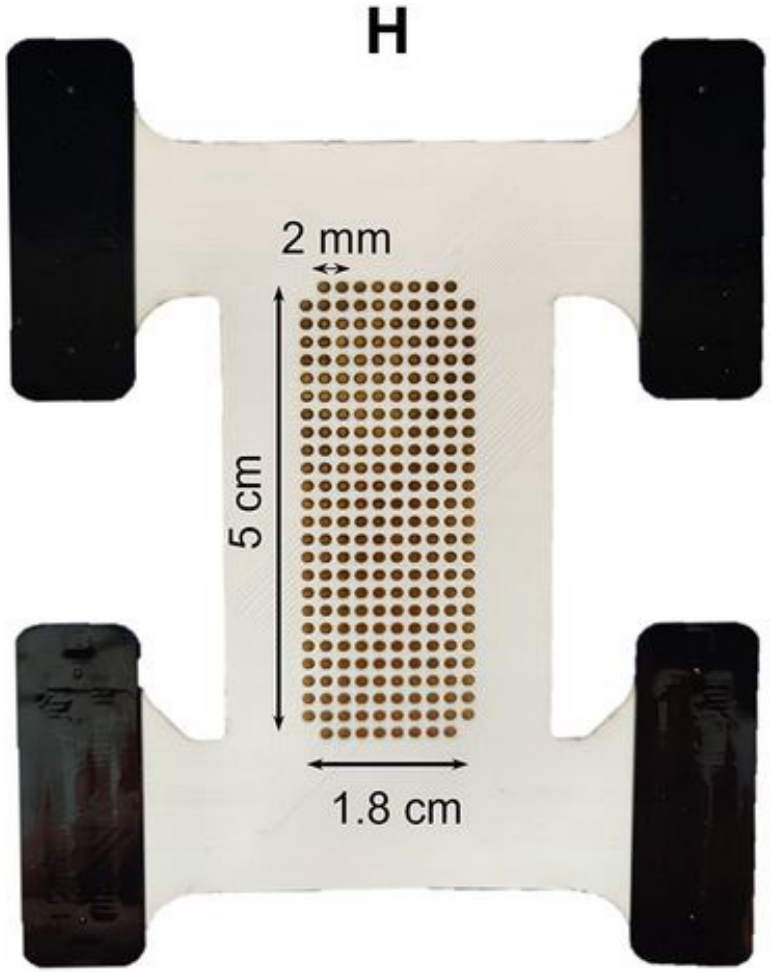
(c) Wearable and modular 64/128 channel amplifier with sleeve electrode array

(d) Flexible mylar array with double adhesive foam.



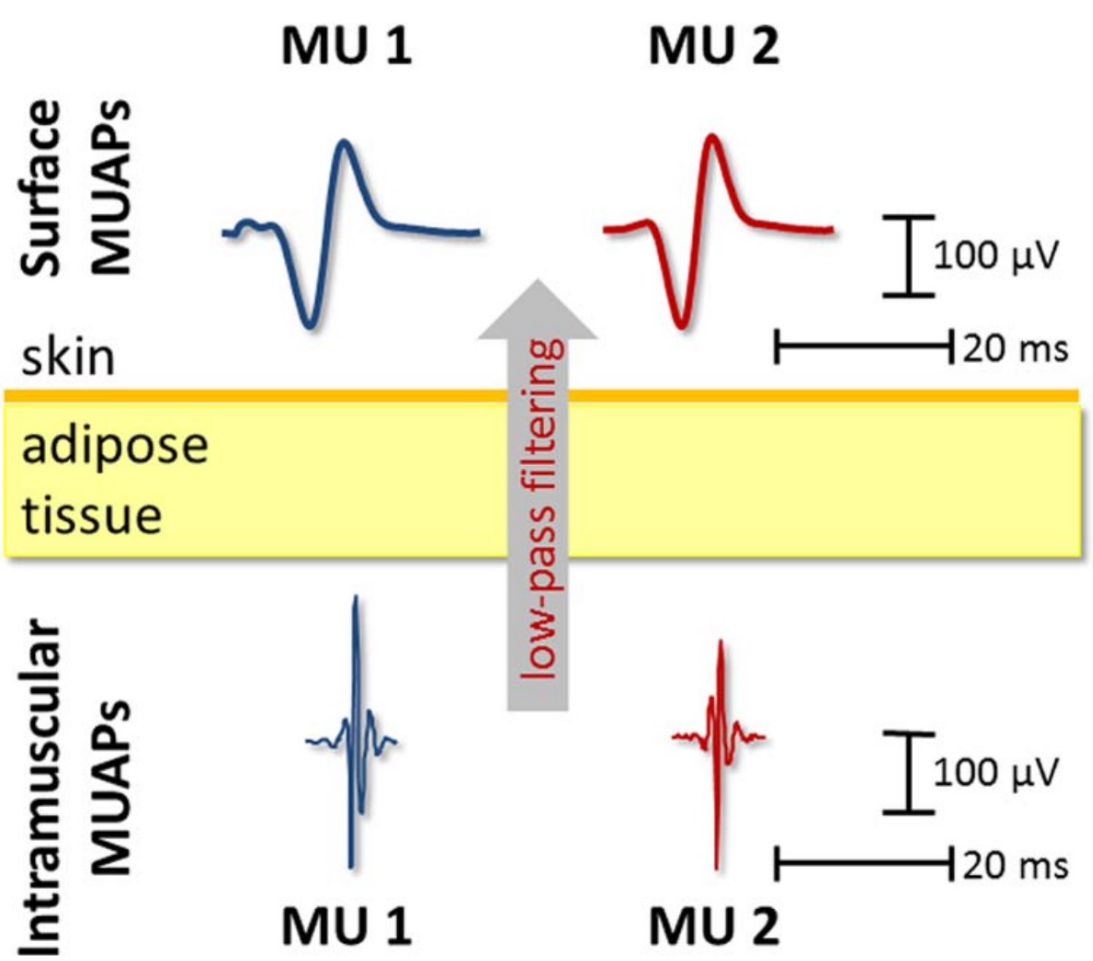
Merletti et al. (2017)

Ultra-dense grids

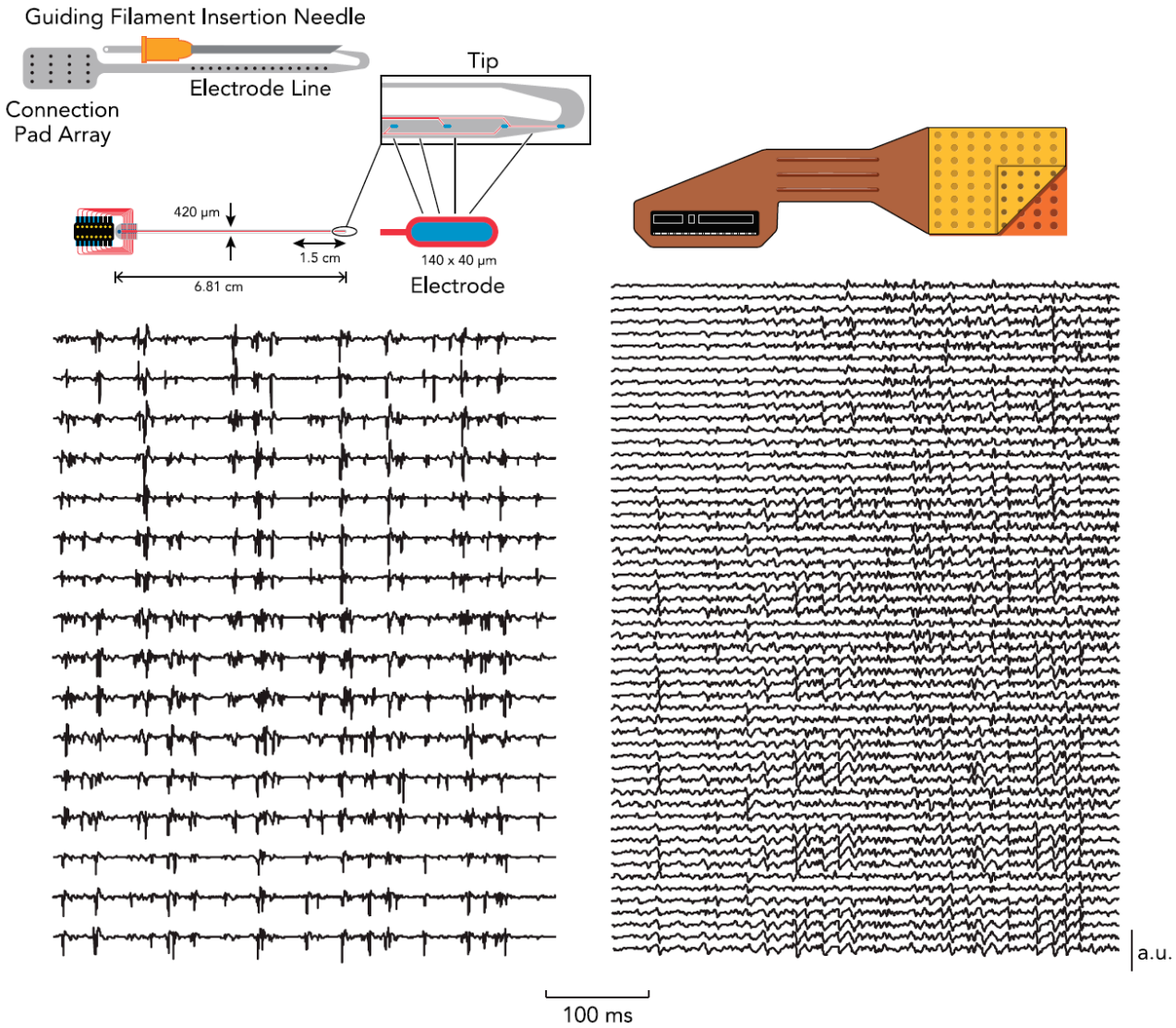


Caillet et al. (2023) eNeuro

EFFECT OF THE VOLUME CONDUCTOR

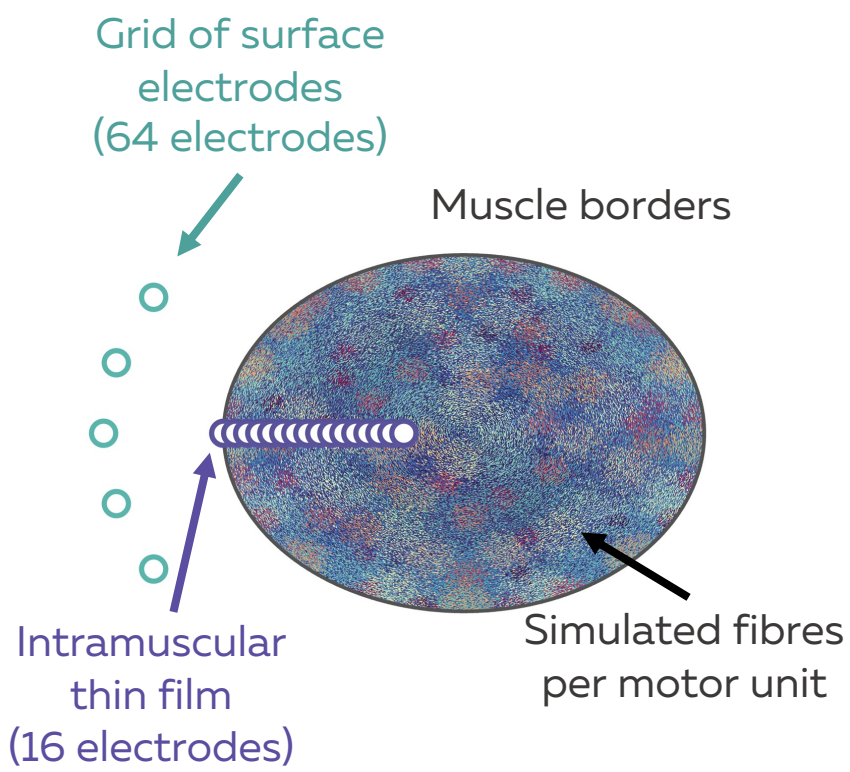


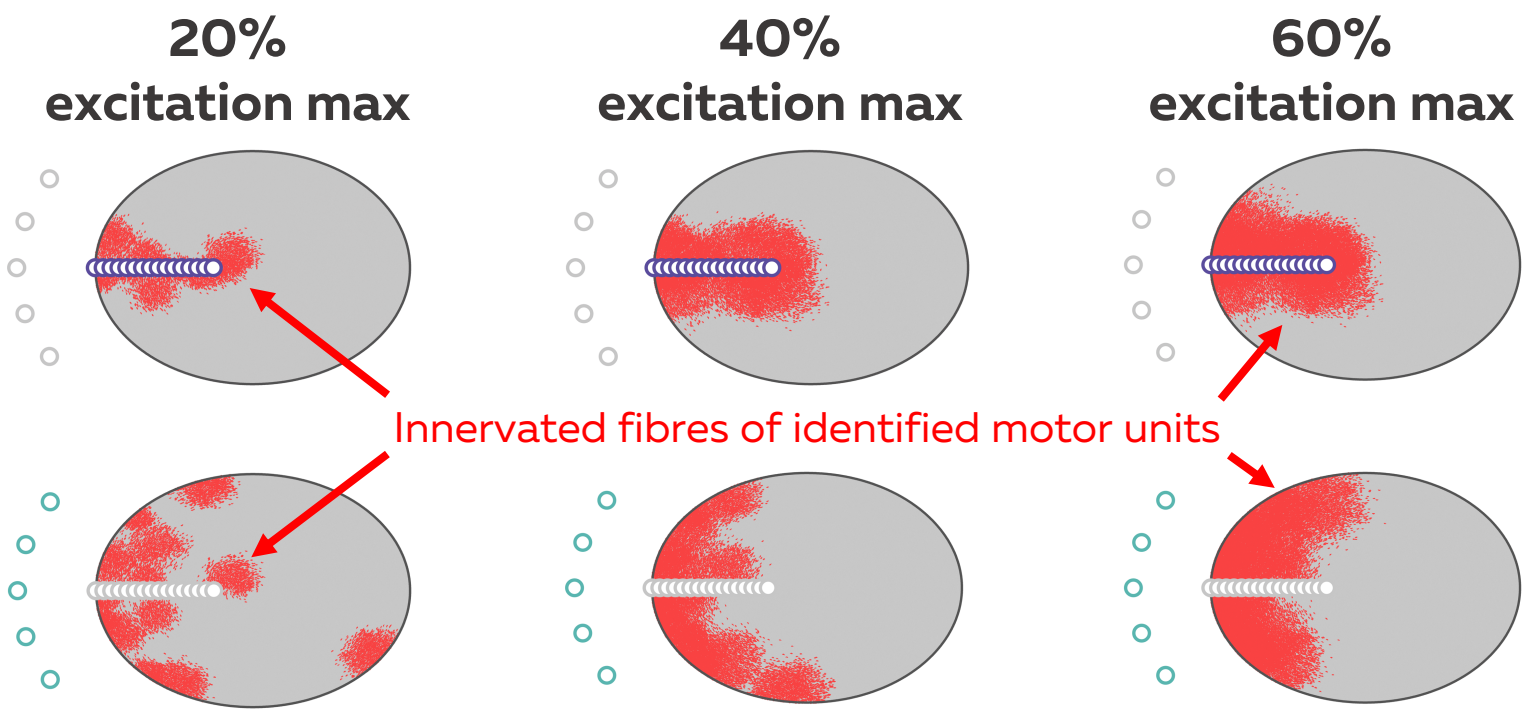
Farina & Holobar (2016) Proceedings of the IEEE



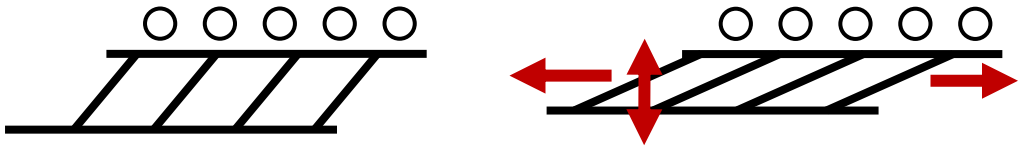
Farina et al. (2016) Physiology

EFFECT OF THE VOLUME CONDUCTOR

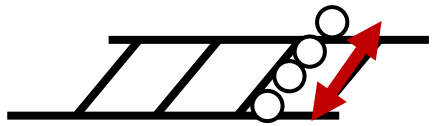




Change in muscle geometry



Drift



INNOVATIONS IN EMG RECORDINGS

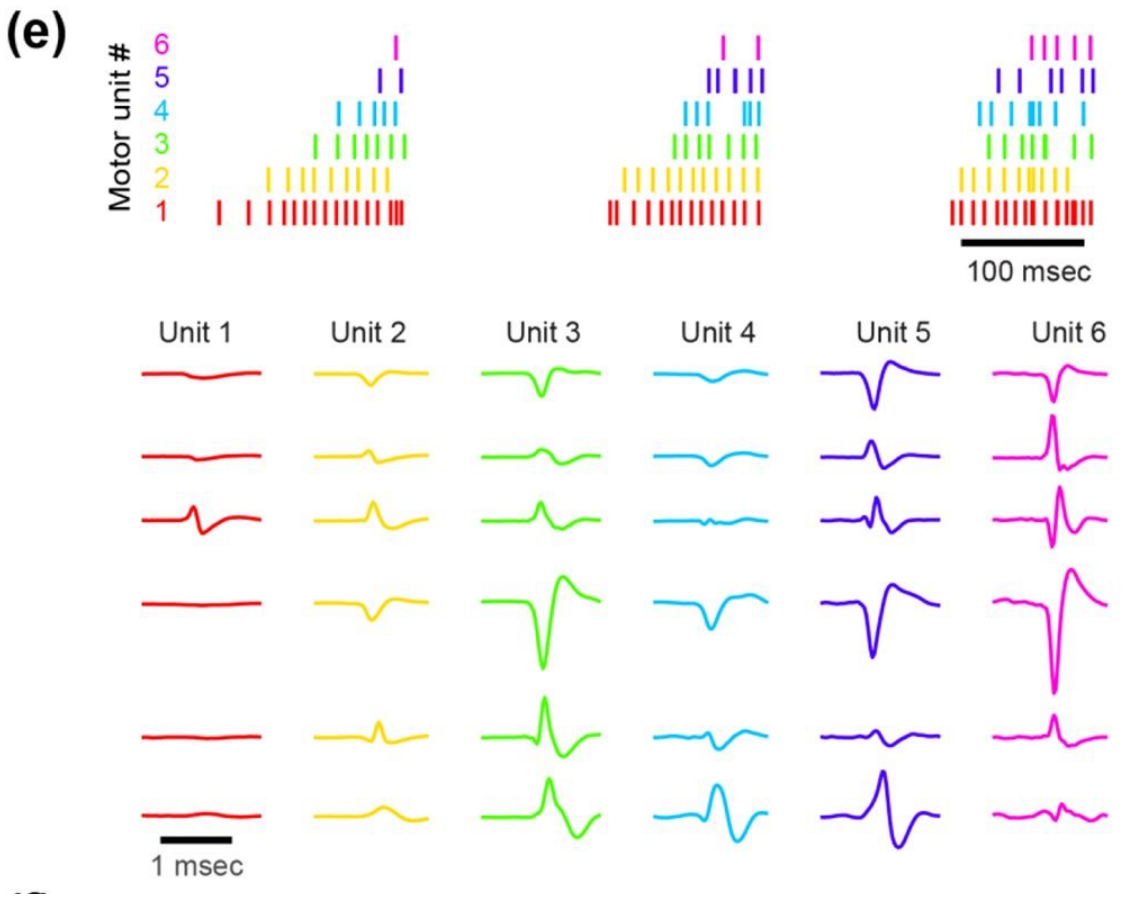
OFFLINE DECOMPOSITION

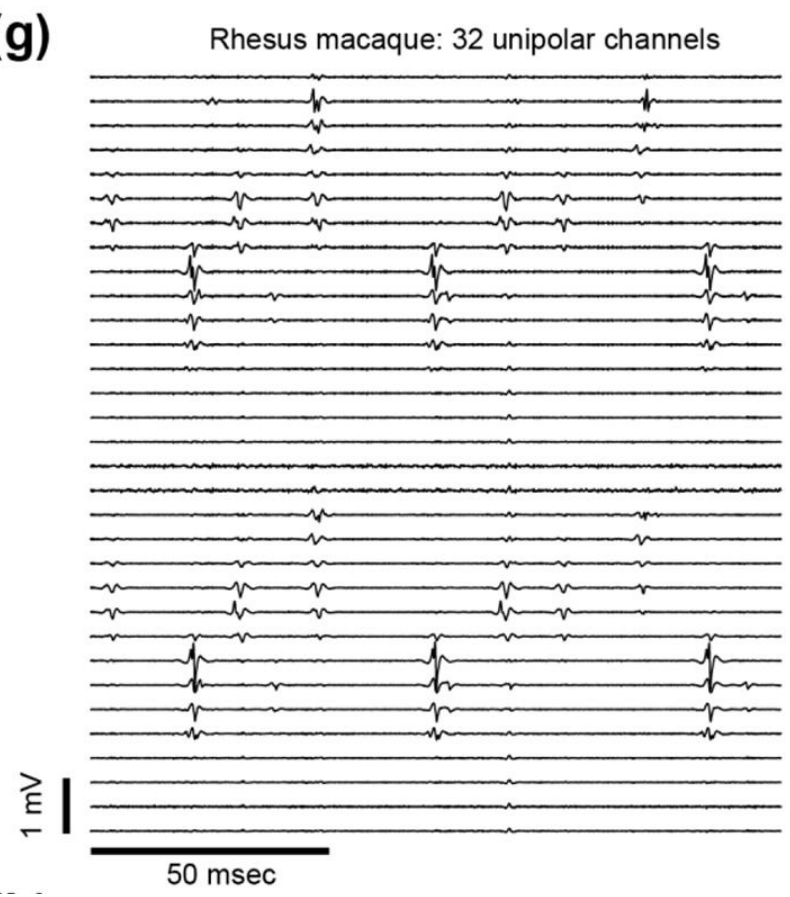
ONLINE DECOMPOSITION

SPIKE SORTING FOR INTRAMUSCULAR EMG

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

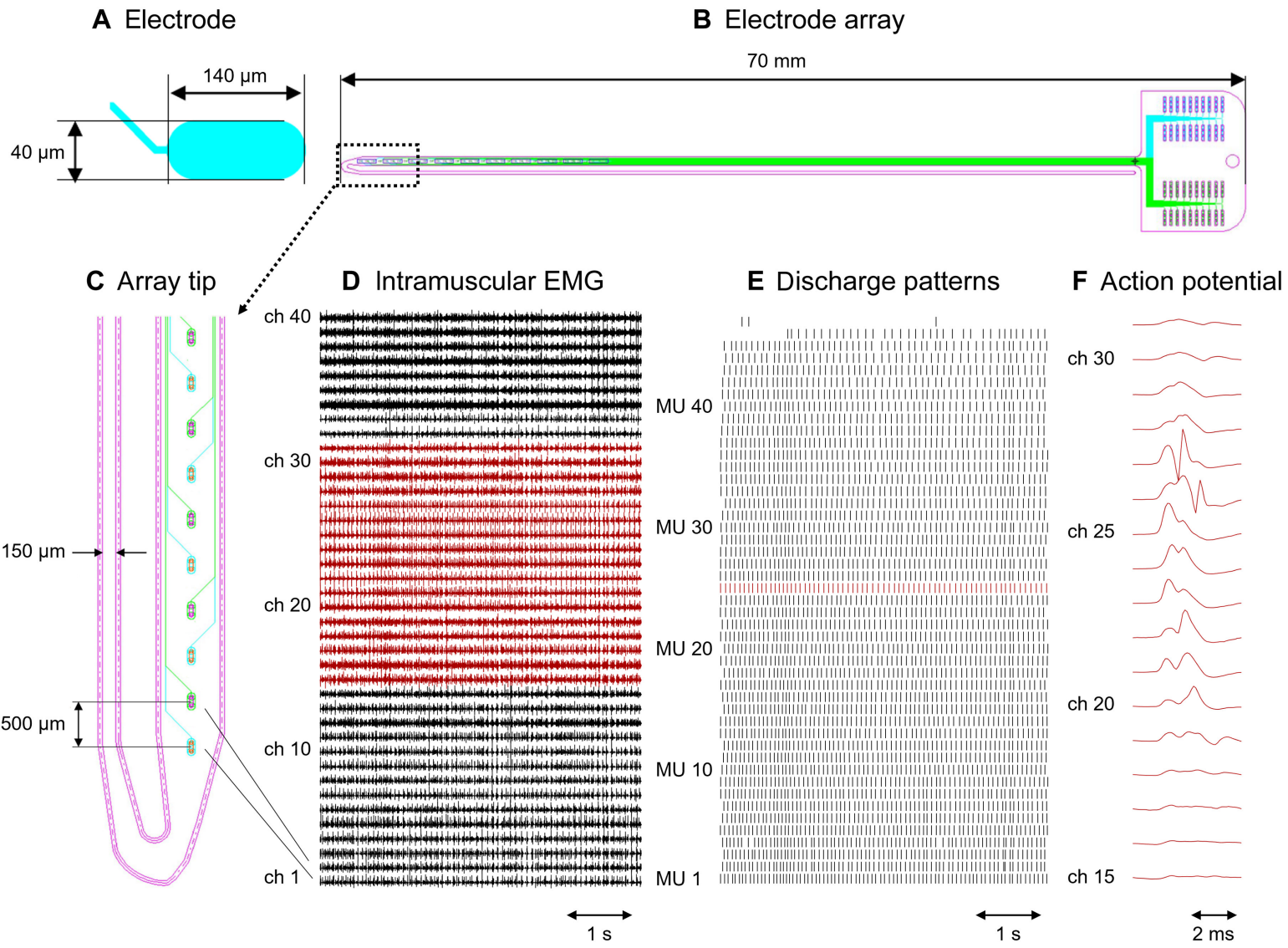
https://github.com/JonathanAMichaels/PixelProcessingPipeline



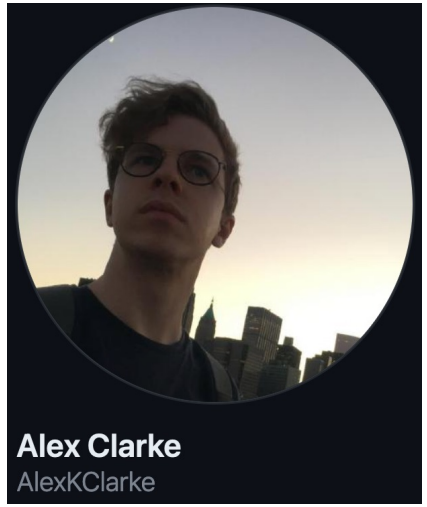


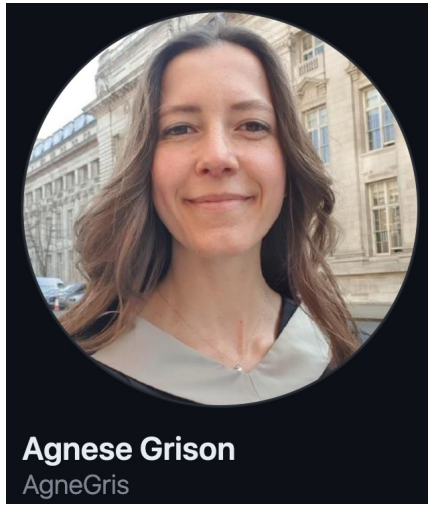
Chung et al. (2023) Elife

EMG DECOMPOSITION USING BLIND-SOURCE SEPARATION



Muceli et al. (2022) Sci Adv





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

Irene Mendez Guerra

Shihan Ma

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[1], Silvia Muceli[1], Anna Margherita Castronovo[1], Ales Holobar[2] and Dario Farina[1]

Published 29 February 2016 • © 2016 IOP Publishing Ltd

Journal of Neural Engineering, Volume 13, Number 2

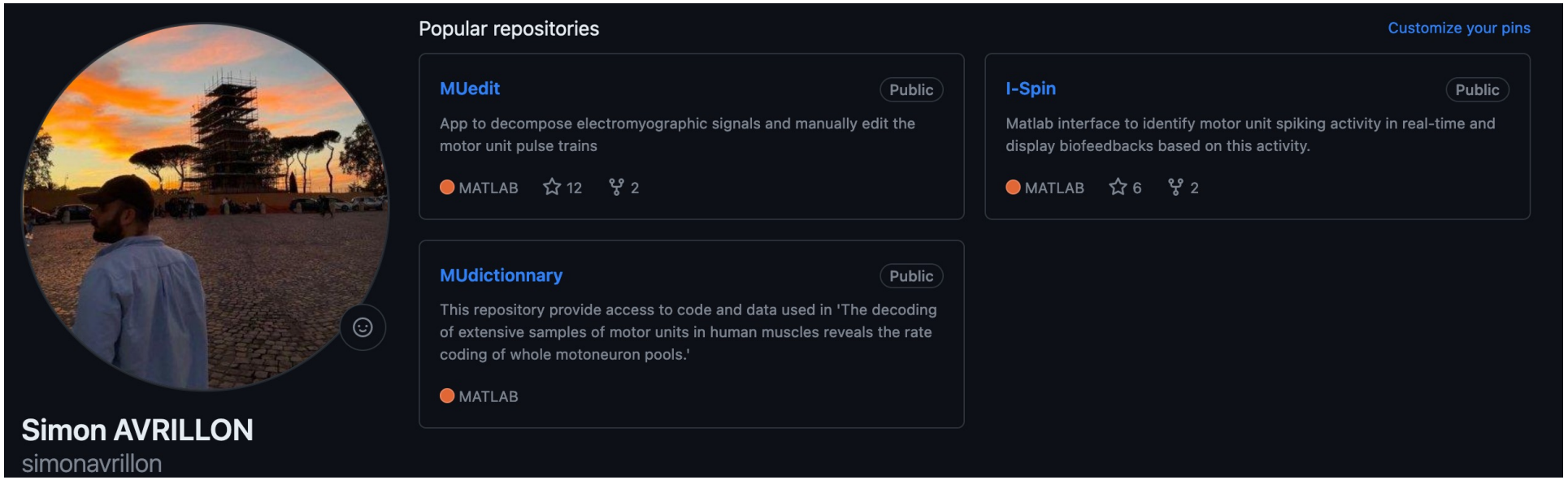
Citation Francesco Negro *et al* 2016 *J. Neural Eng.* **13** 026027

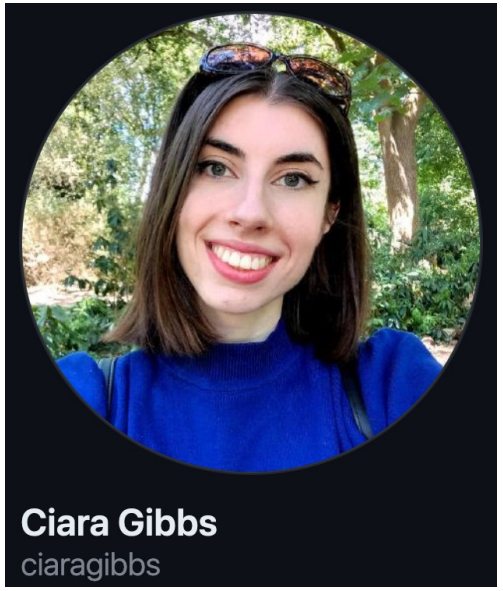
Jiang et al. (2021) IEEE Trans Neural Syst Rehabil Eng
https://physionet.org/content/hd-semg/1.0.0/

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

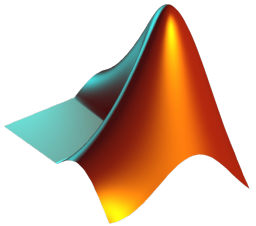
Formento et al. (2021) J Neural Eng
https://github.com/carmenalab/emgdecomp

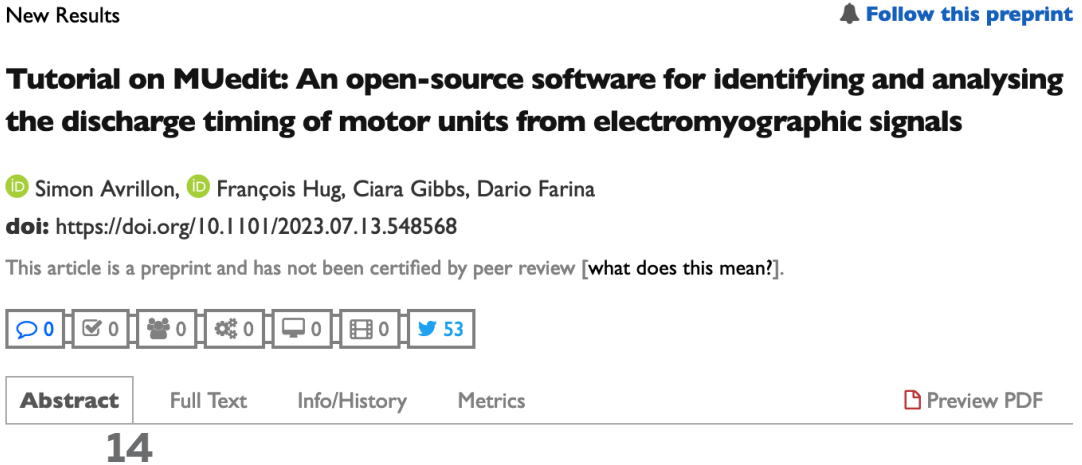
EMG DECOMPOSITION USING BLIND-SOURCE SEPARATION



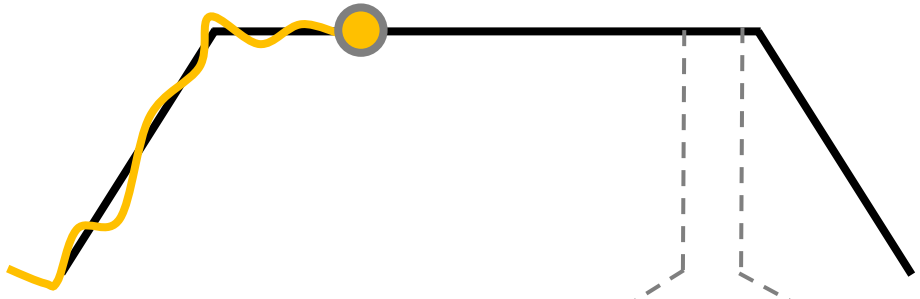


https://github.com/simonavrillon
https://github.com/ciaragibbs



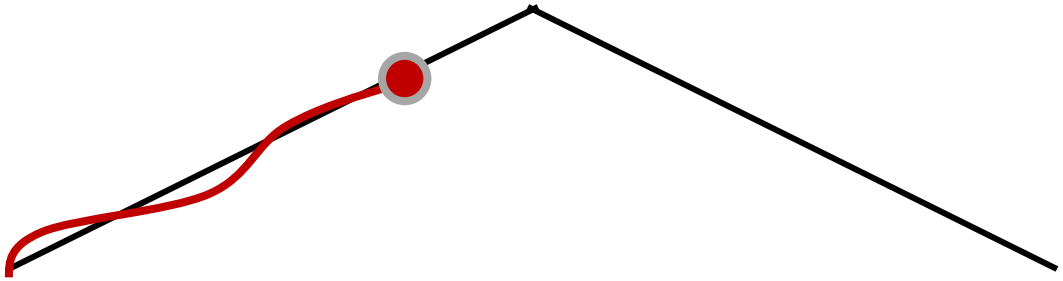


EXPERIMENTAL SETUP



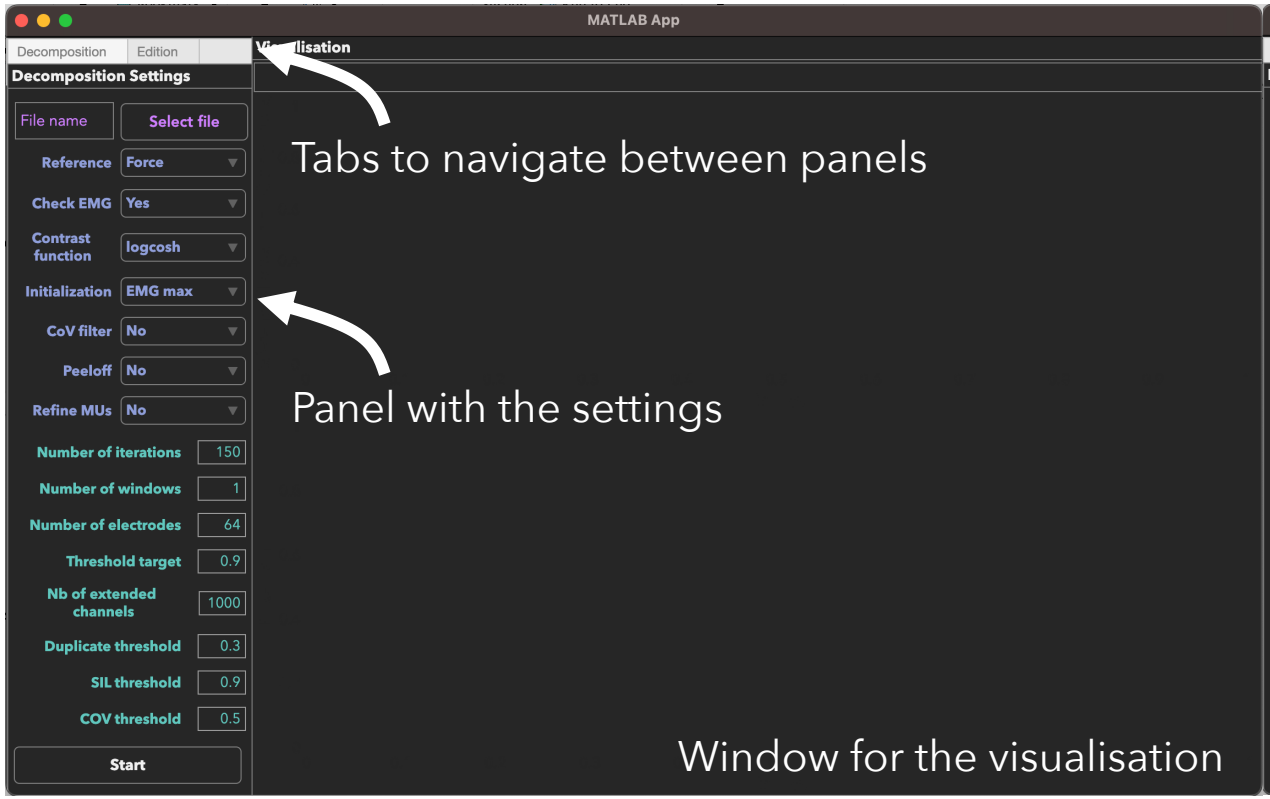
Trapezoidal contraction

Triangular contraction

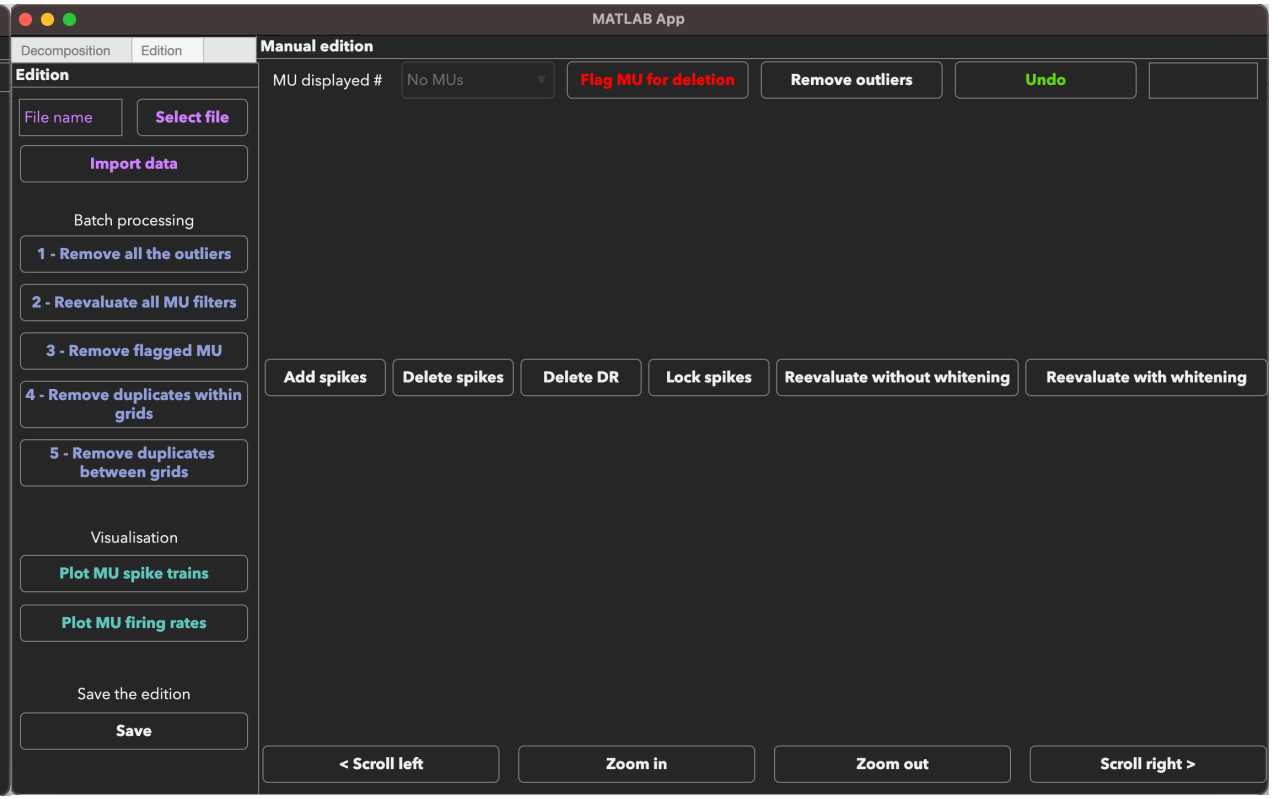


MUedit

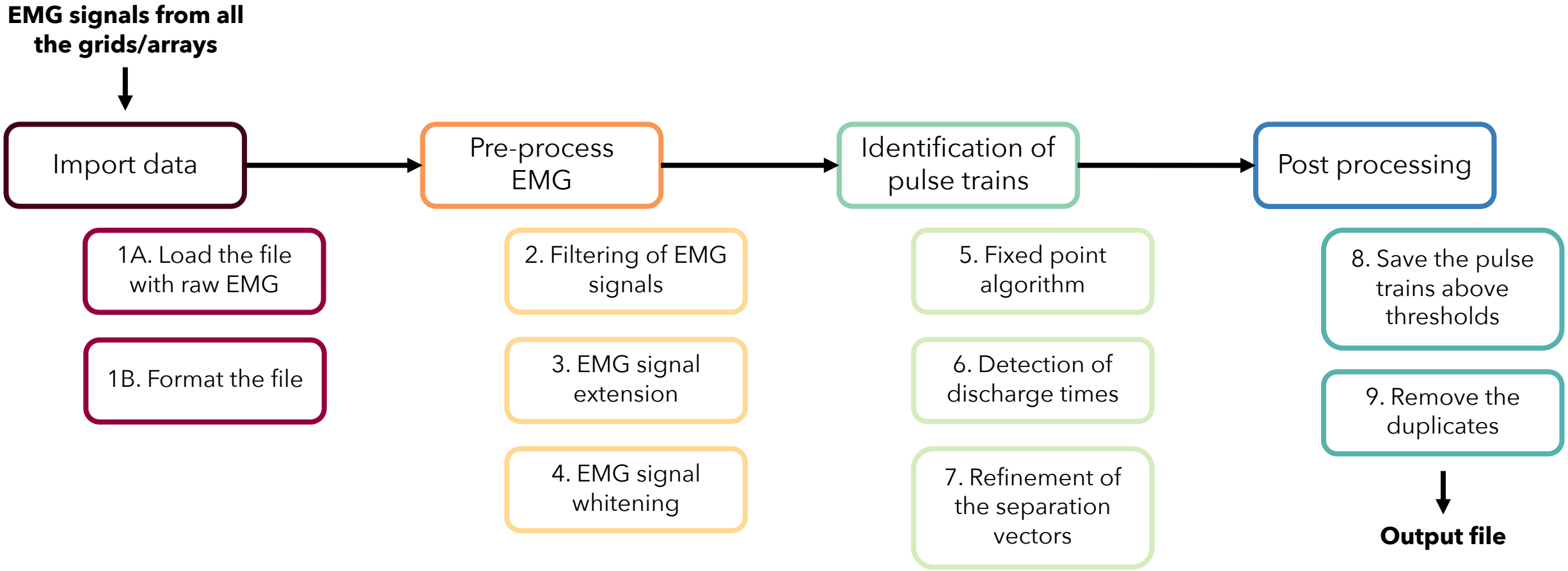
Decomposition panel

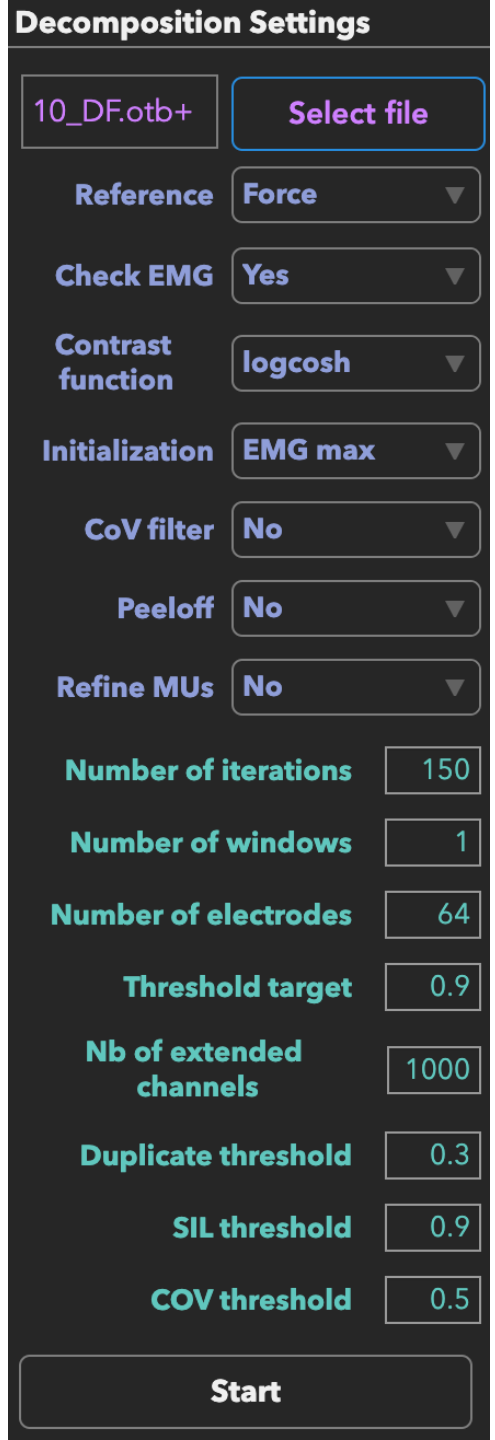


Edition panel



FRAMEWORK FOR OFFLINE EMG DECOMPOSITION





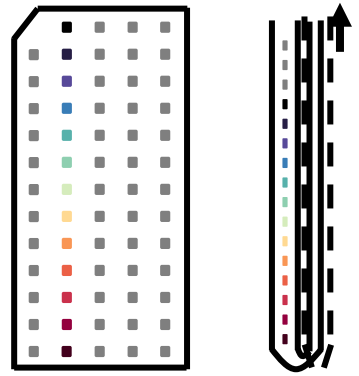
Button to import ‘otb+’ or ‘mat’ files

Options for the decomposition

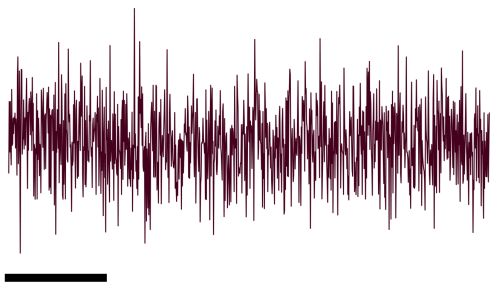
Parameters for the decomposition

Button to start the decomposition

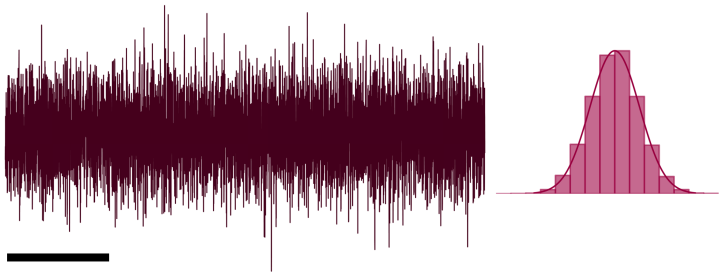
OPTIMISATION OF SEPARATION VECTORS



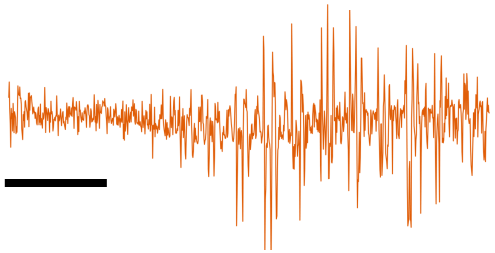
Initialisation of the separation vector



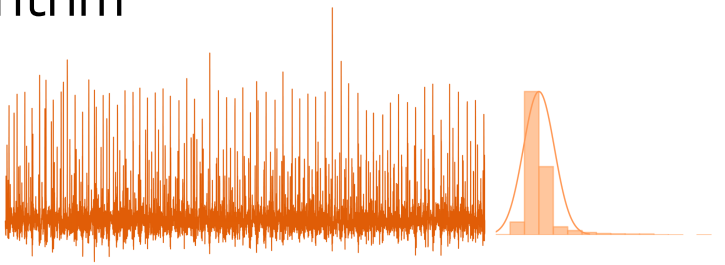
Iteration #1

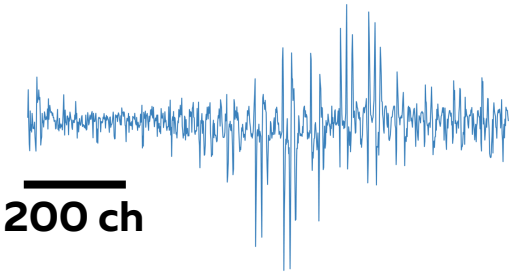


Fixed-point algorithm

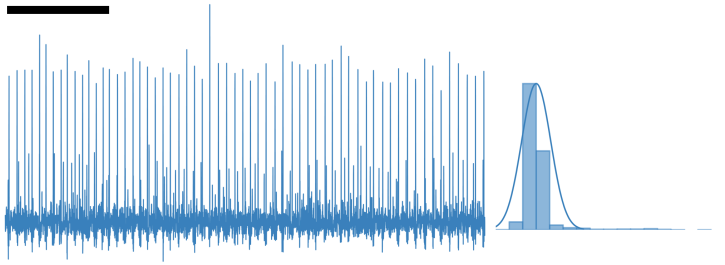


Iteration #5



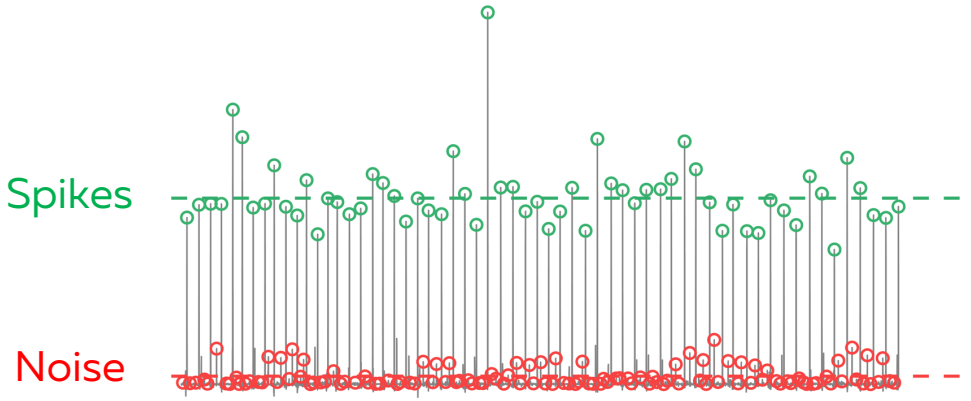


Iteration #10



200 ch

1 s

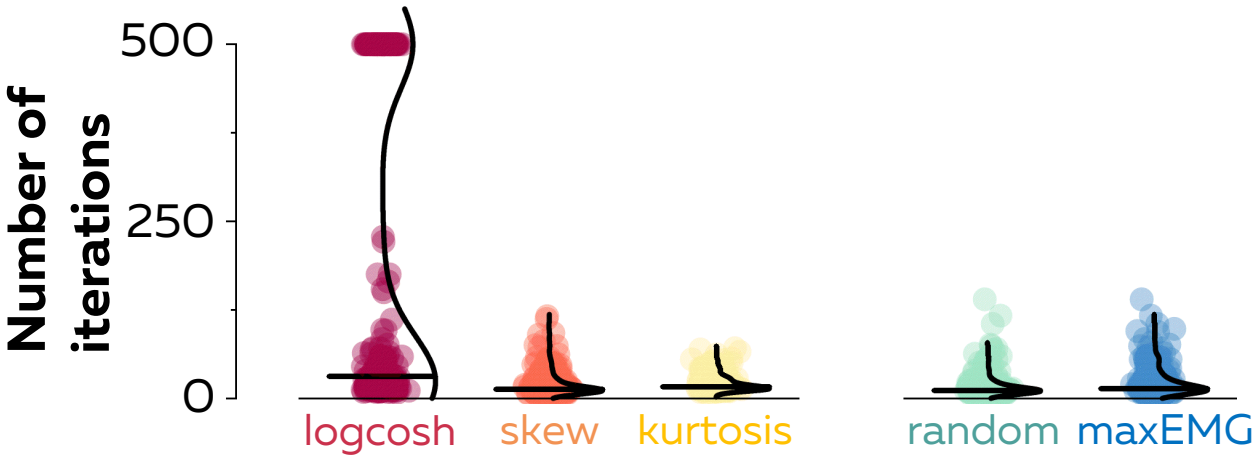


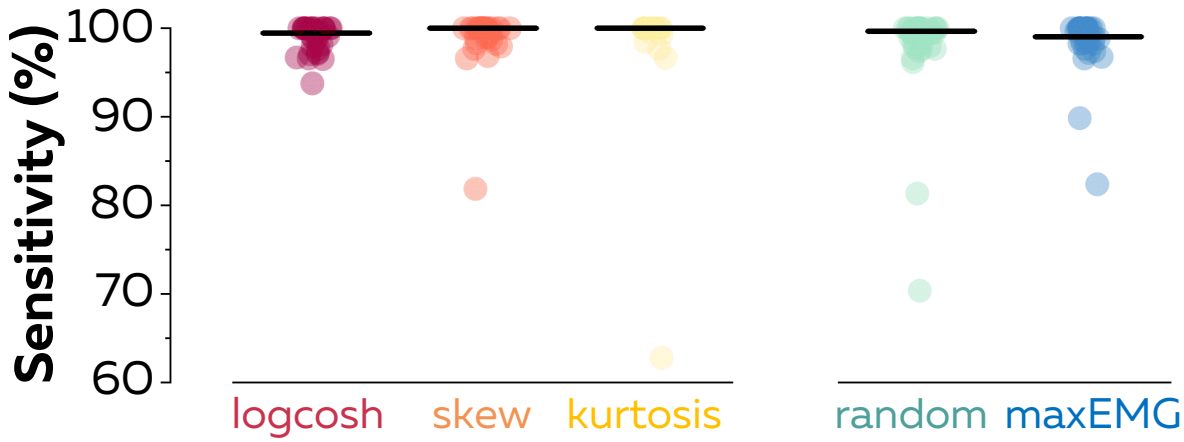
1 s

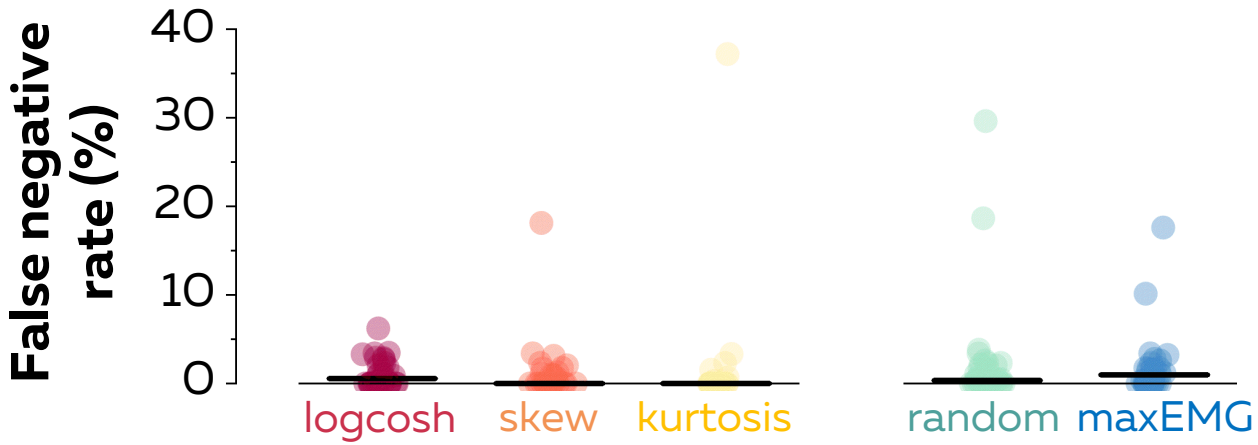
Refinement of the motor unit pulse train

Peak detection and classification

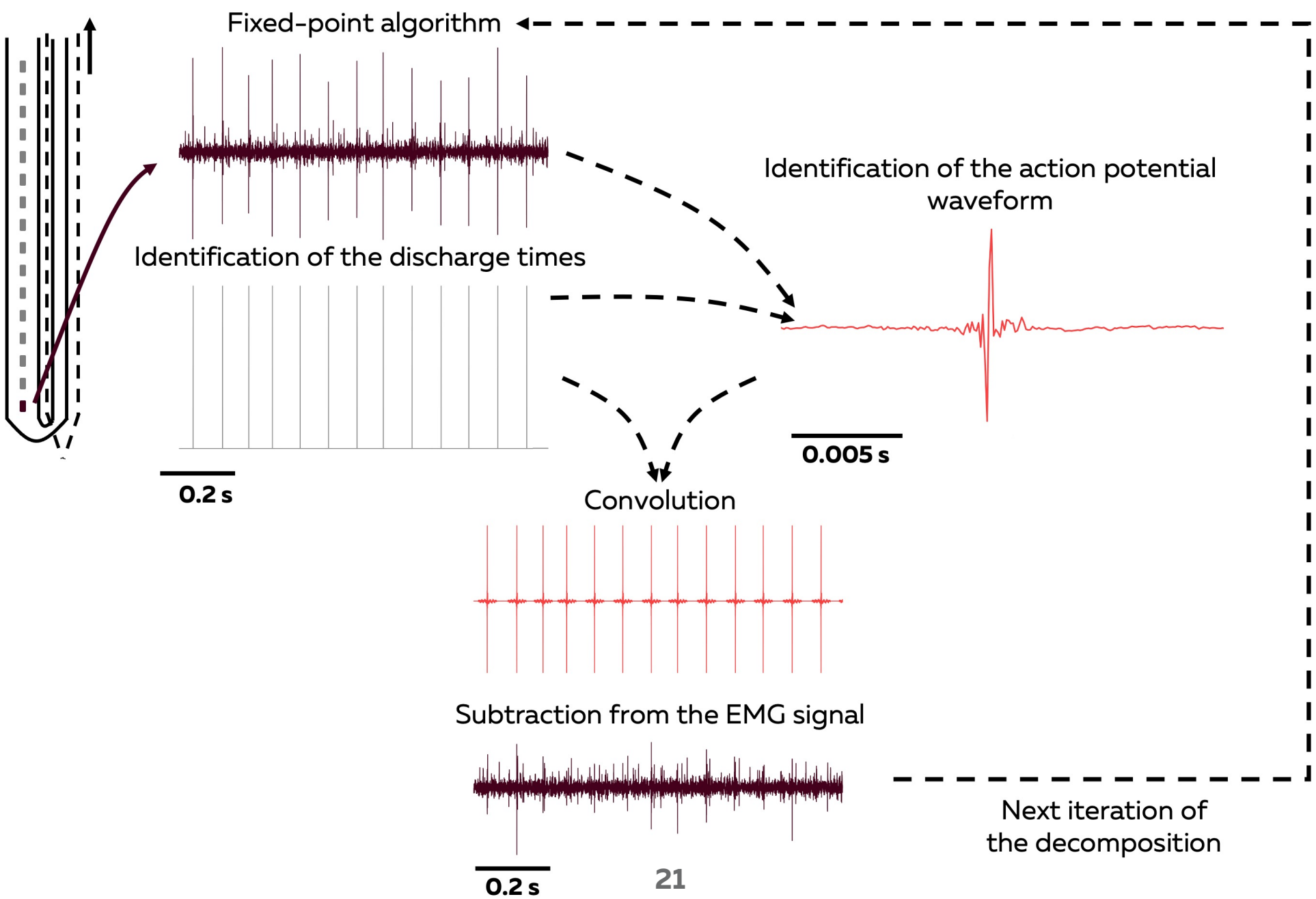
OPTIMISATION OF SEPARATION VECTORS



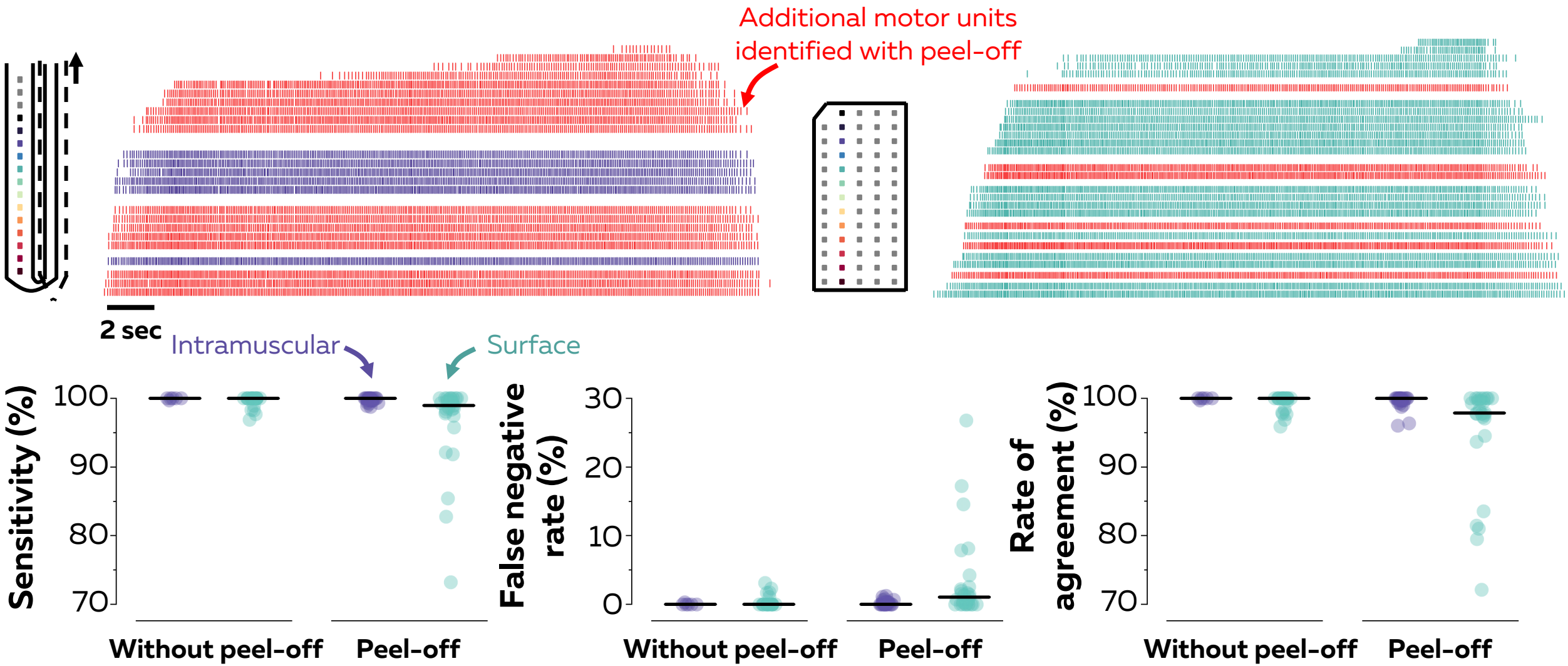


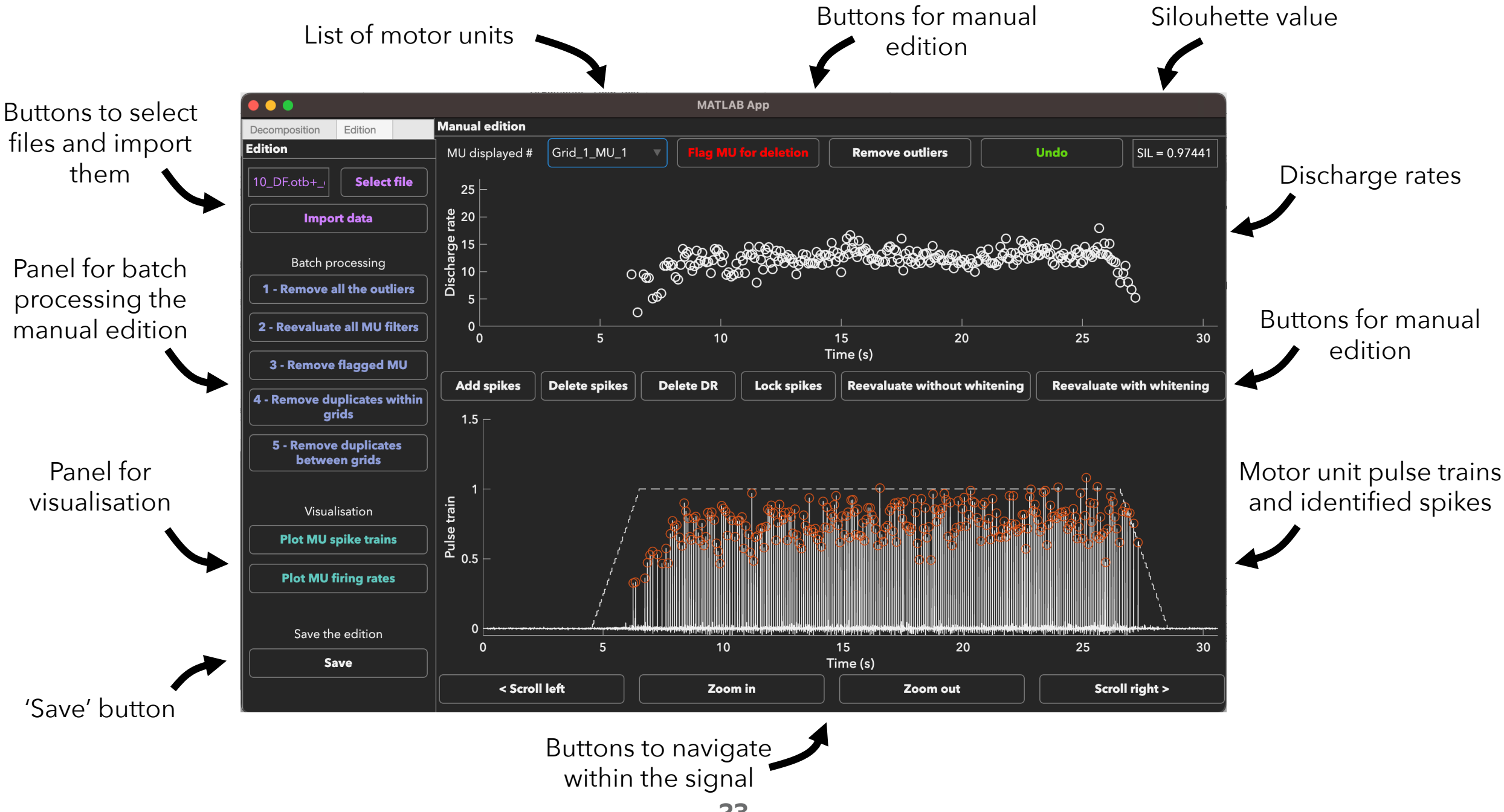


PEEL-OFF

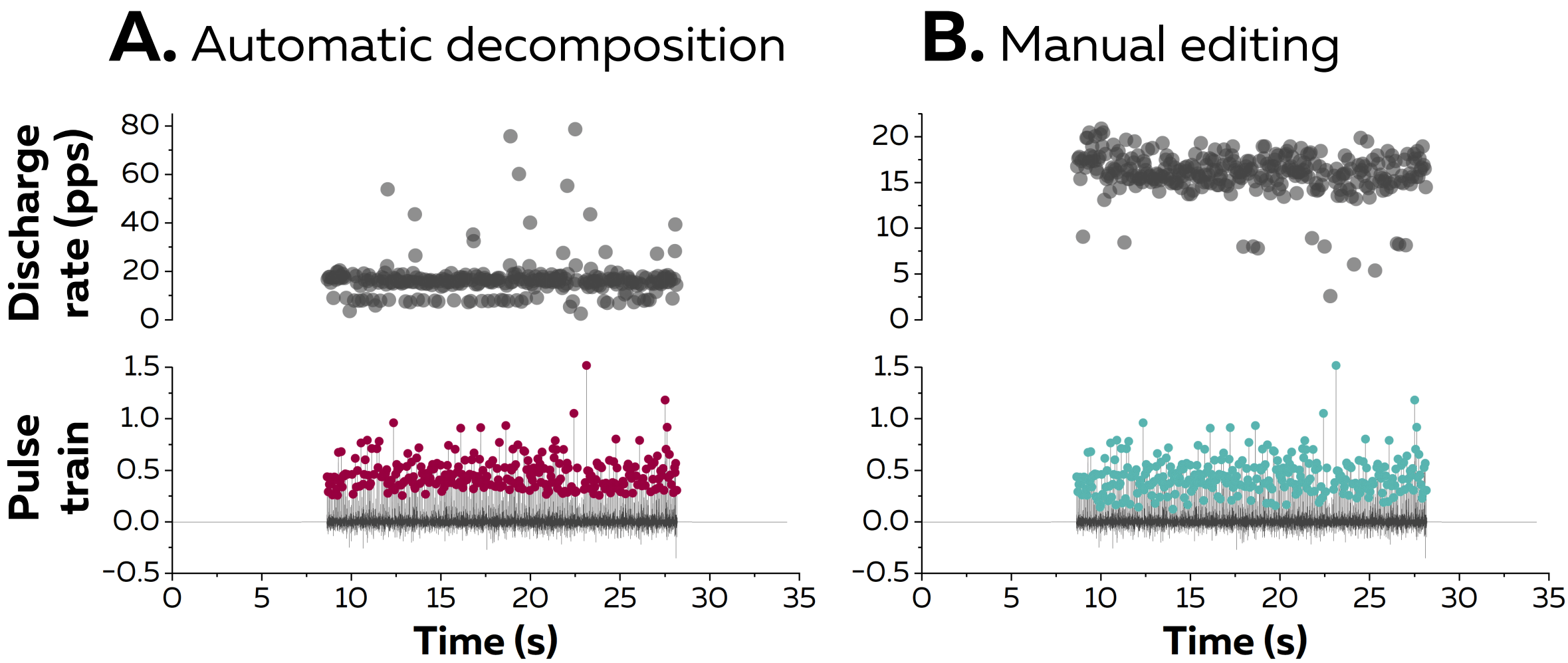

Fixed-point algorithm
Identification of the discharge times
0.2 s
Identification of the action potential waveform
0.005 s
Convolution
Subtraction from the EMG signal
0.2 s
Next iteration of the decomposition

PEEL-OFF


Additional motor units
identified with peel-off
2 sec
Intramuscular
Surface
Sensitivity (%)
100
90
80
70
Without peel-off
Peel-off
False negative
rate (%)
30
20
10
0
Without peel-off
Peel-off
Rate of
agreement (%)
100
90
80
70
Without peel-off
Peel-off


List of motor units
Buttons for manual edition
Silouhette value
Buttons to select files and import them
Discharge rates
Panel for batch processing the manual edition
Buttons for manual edition
Panel for visualisation
Motor unit pulse trains and identified spikes
'Save' button
Buttons to navigate within the signal
MATLAB App
Decomposition
Edition
Edition
10_DF.otb+_
Select file
Import data
Batch processing
1 - Remove all the outliers
2 - Reevaluate all MU filters
3 - Remove flagged MU
4 - Remove duplicates within grids
5 - Remove duplicates between grids
Visualisation
Plot MU spike trains
Plot MU firing rates
Save the edition
Save
Manual edition
MU displayed #
Grid_1_MU_1
Flag MU for deletion
Remove outliers
Undo
SIL = 0.97441
Discharge rate
Time (s)
Add spikes
Delete spikes
Delete DR
Lock spikes
Reevaluate without whitening
Reevaluate with whitening
Pulse train
Time (s)
< Scroll left
Zoom in
Zoom out
Scroll right >

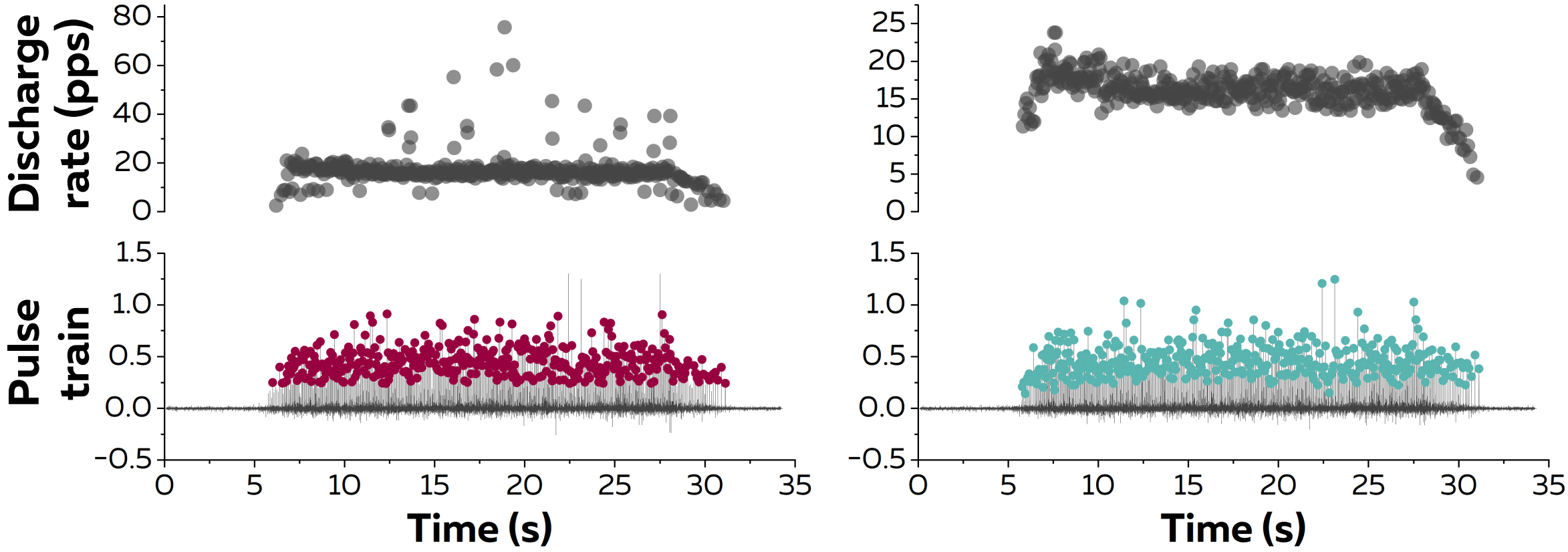
MANUAL EDITING



MANUAL EDITING

C. Recalculation of the separation vector

D. Manual editing

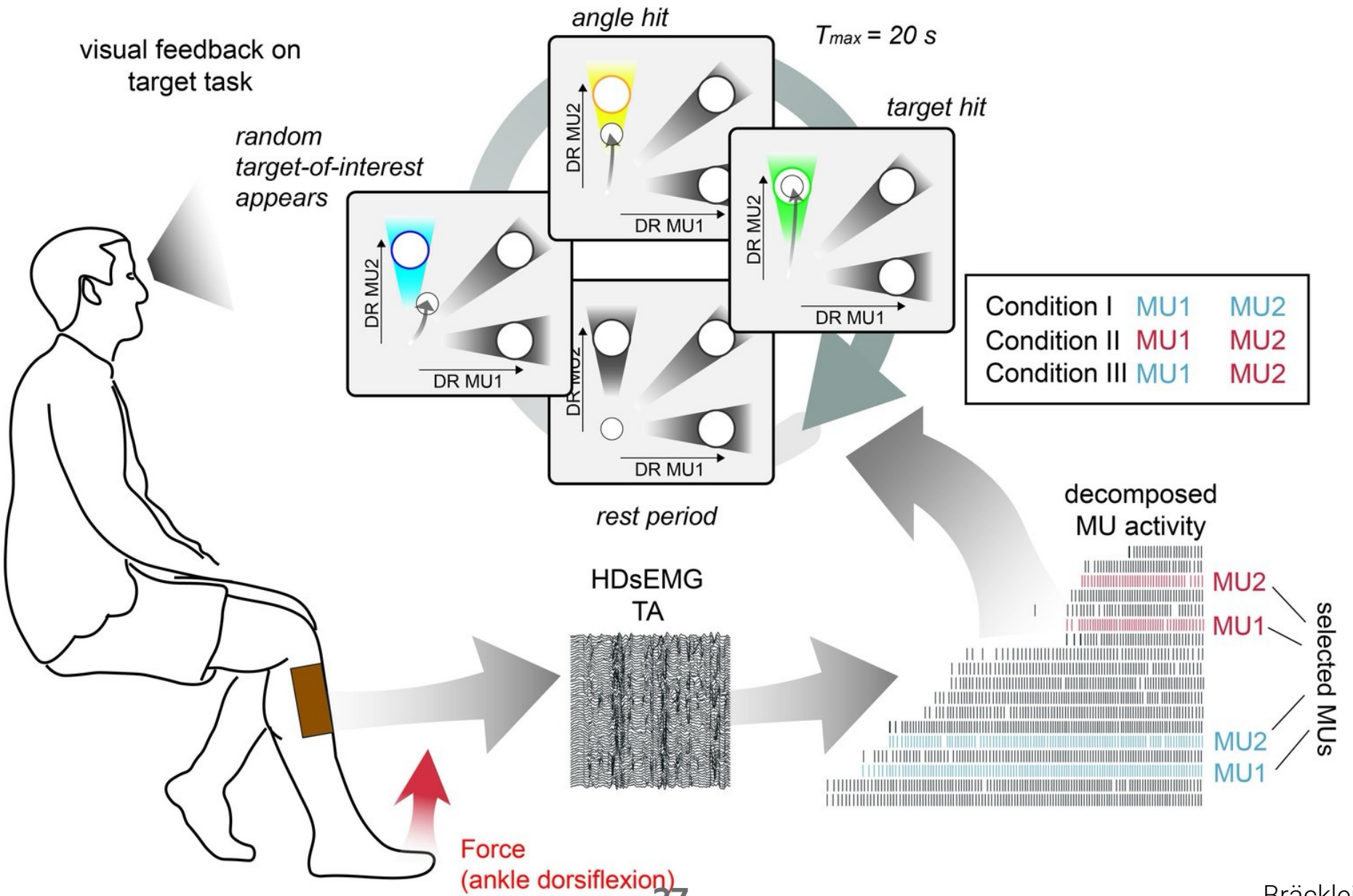


INNOVATIONS IN EMG RECORDINGS

OFFLINE DECOMPOSITION

ONLINE DECOMPOSITION

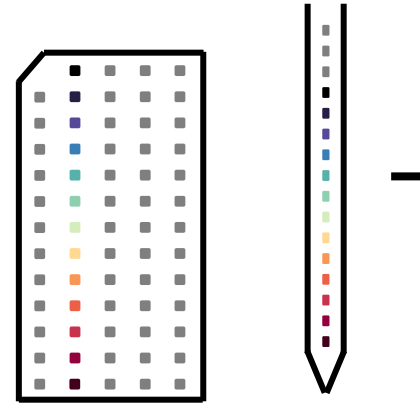
NEURAL CONSTRAINTS ON MOTOR UNIT CONTROL

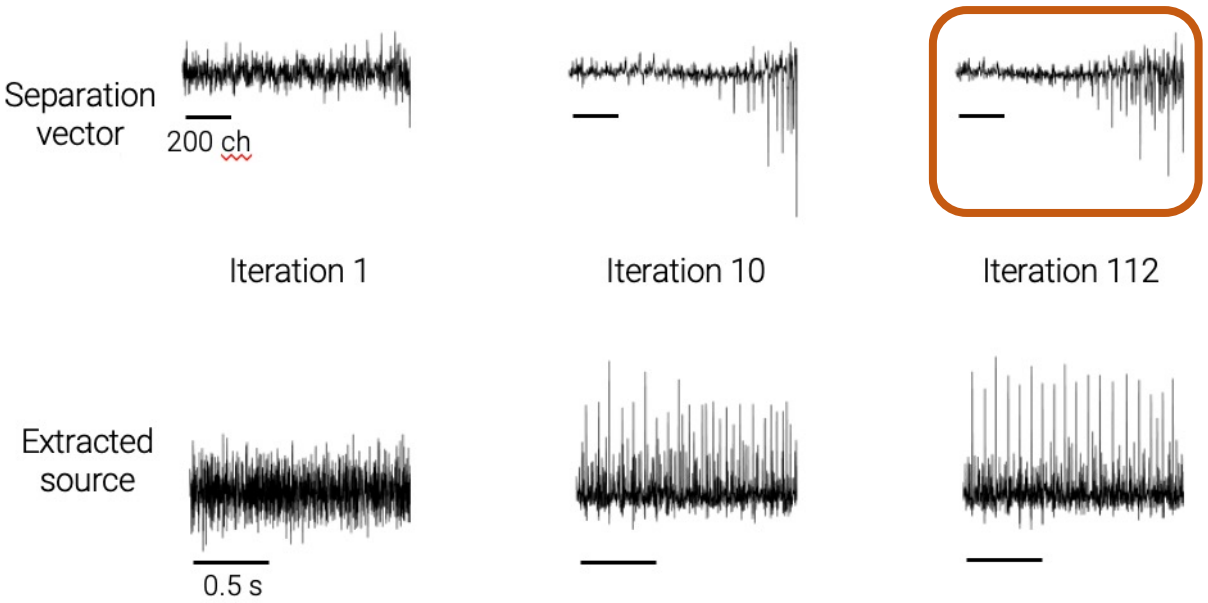


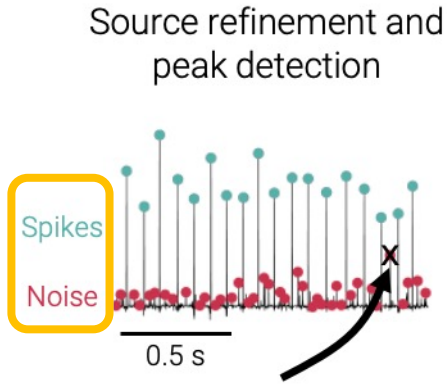
Bräcklein et al. (2022) Elife

ONLINE EMG DECOMPOSITION WITH I-SPIN LIVE

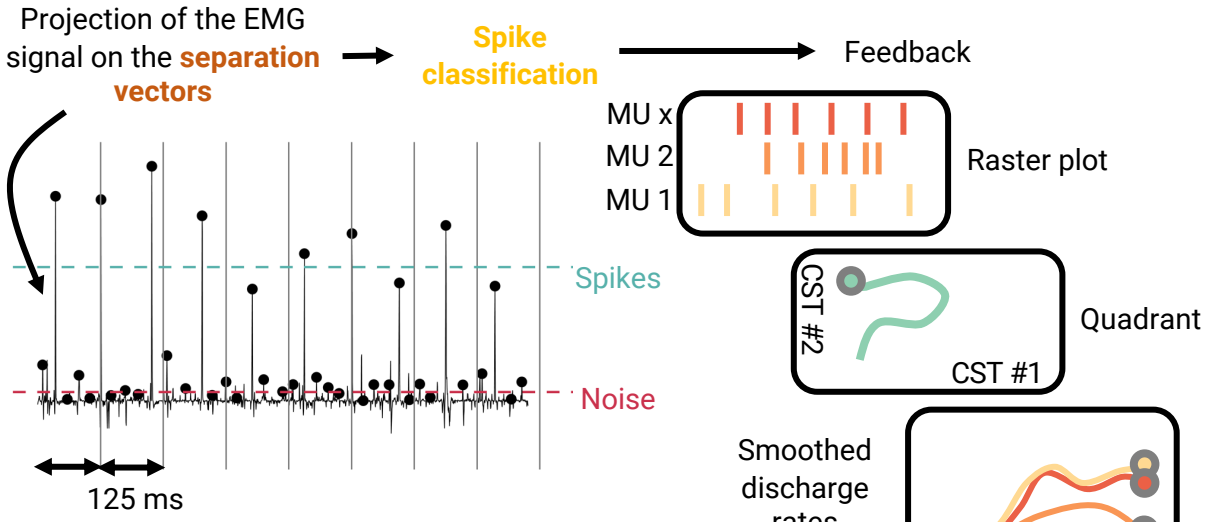
CALIBRATION

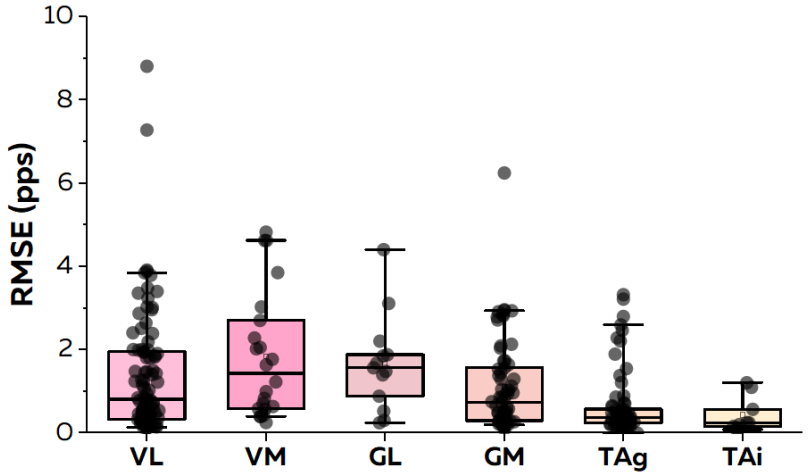






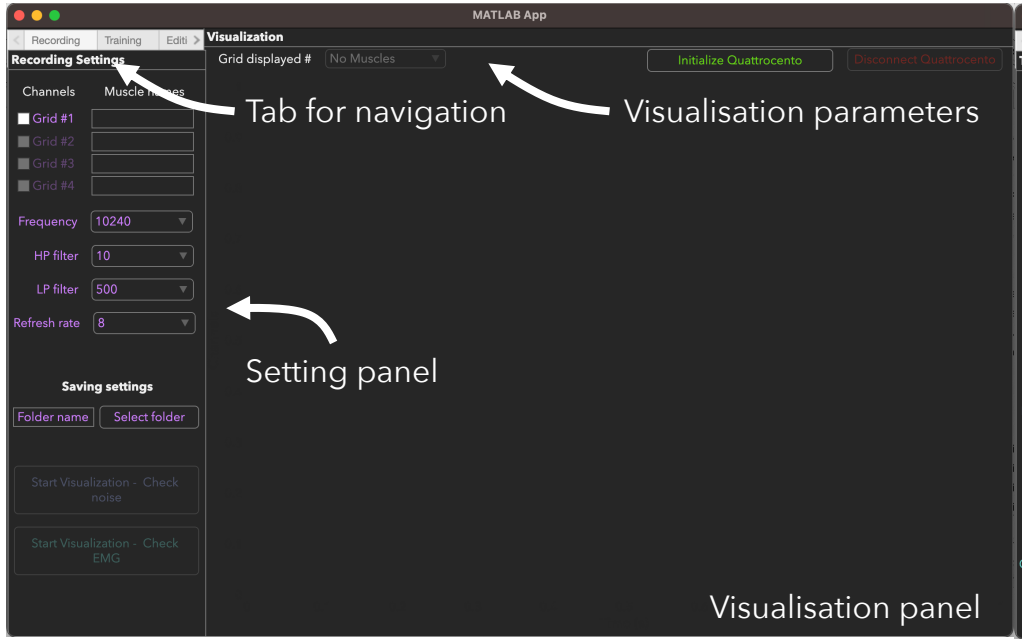
ONLINE



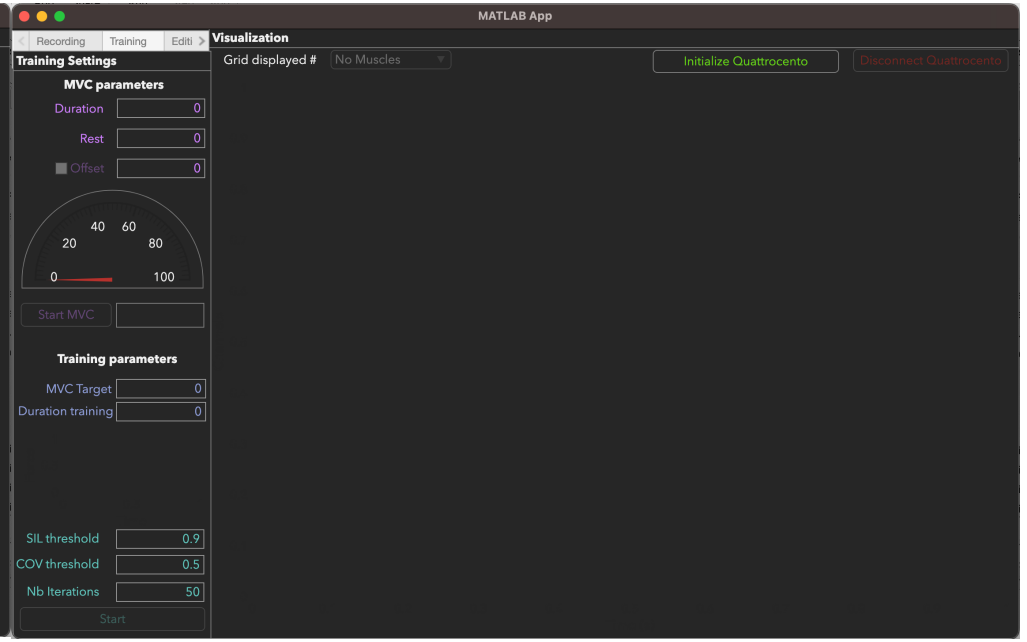


Rossato et al. (2023) eLife
simonavrillon/I-Spin

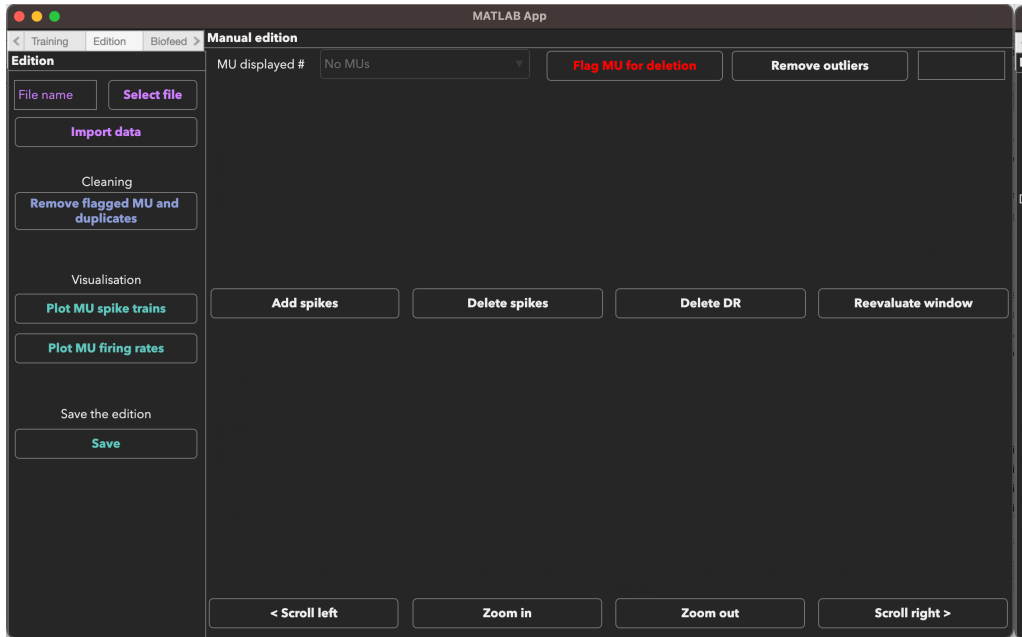
1. Recording panel



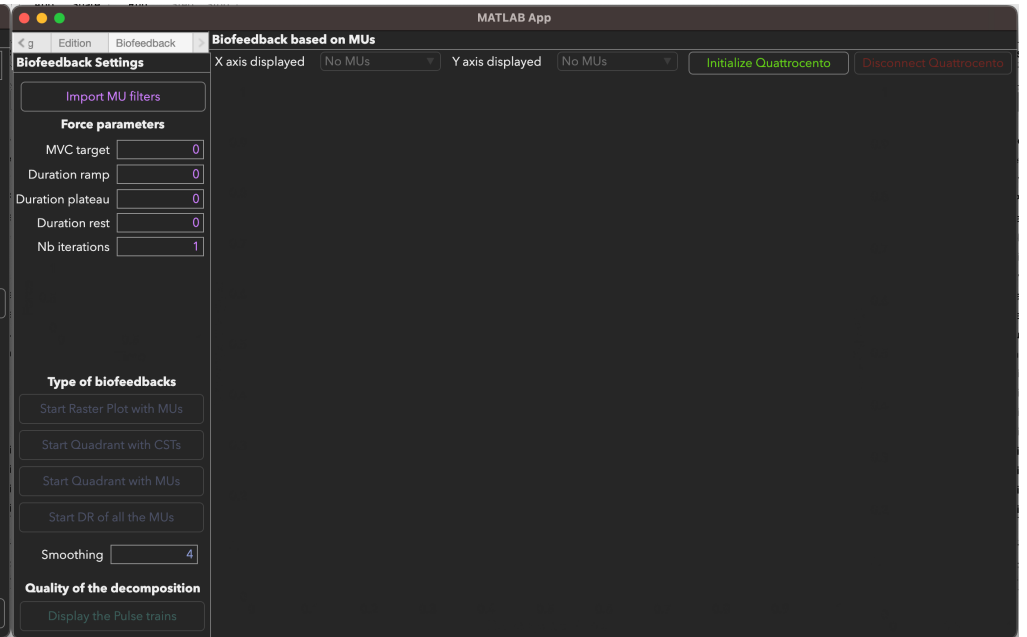
2. Training panel

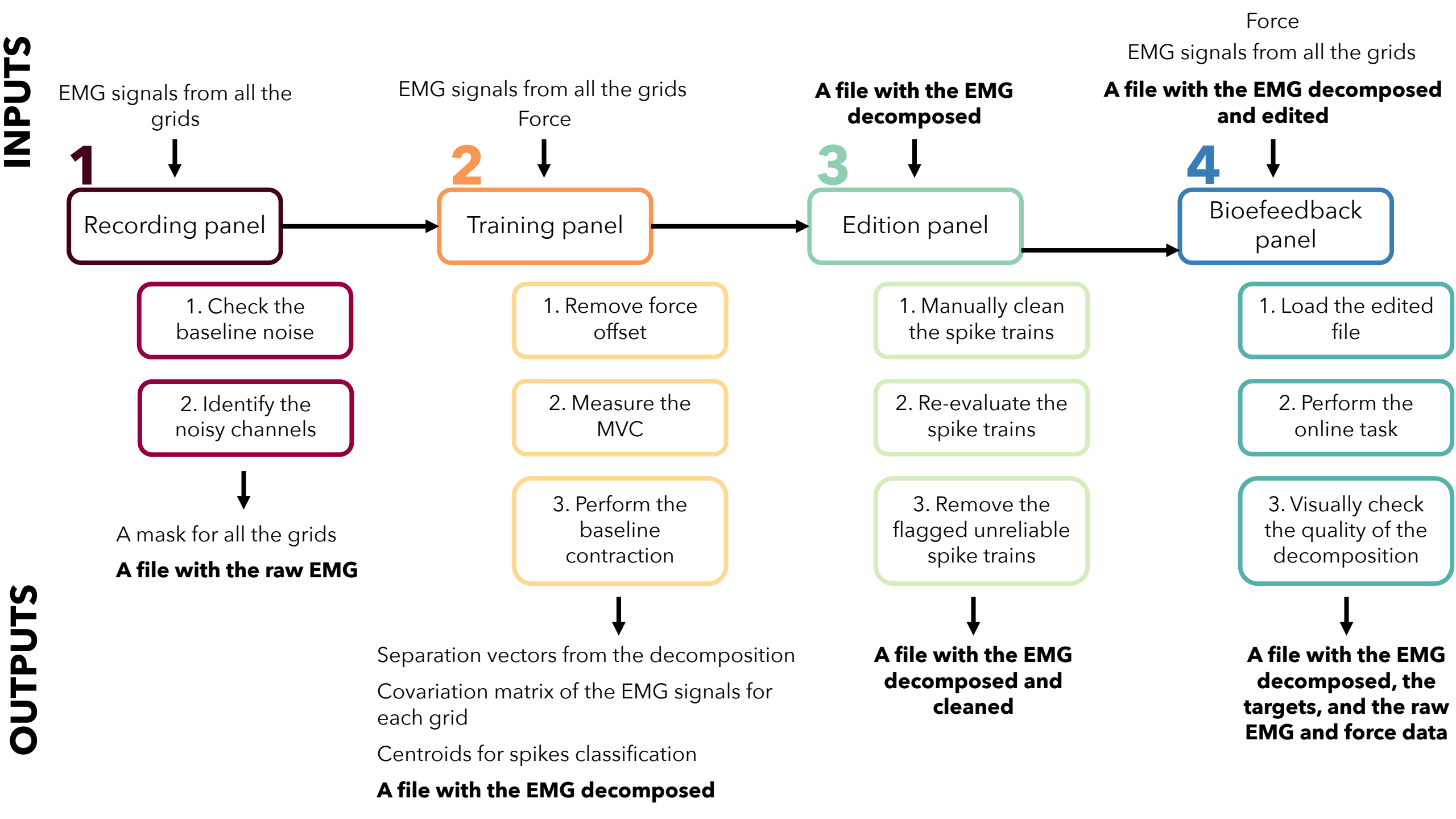


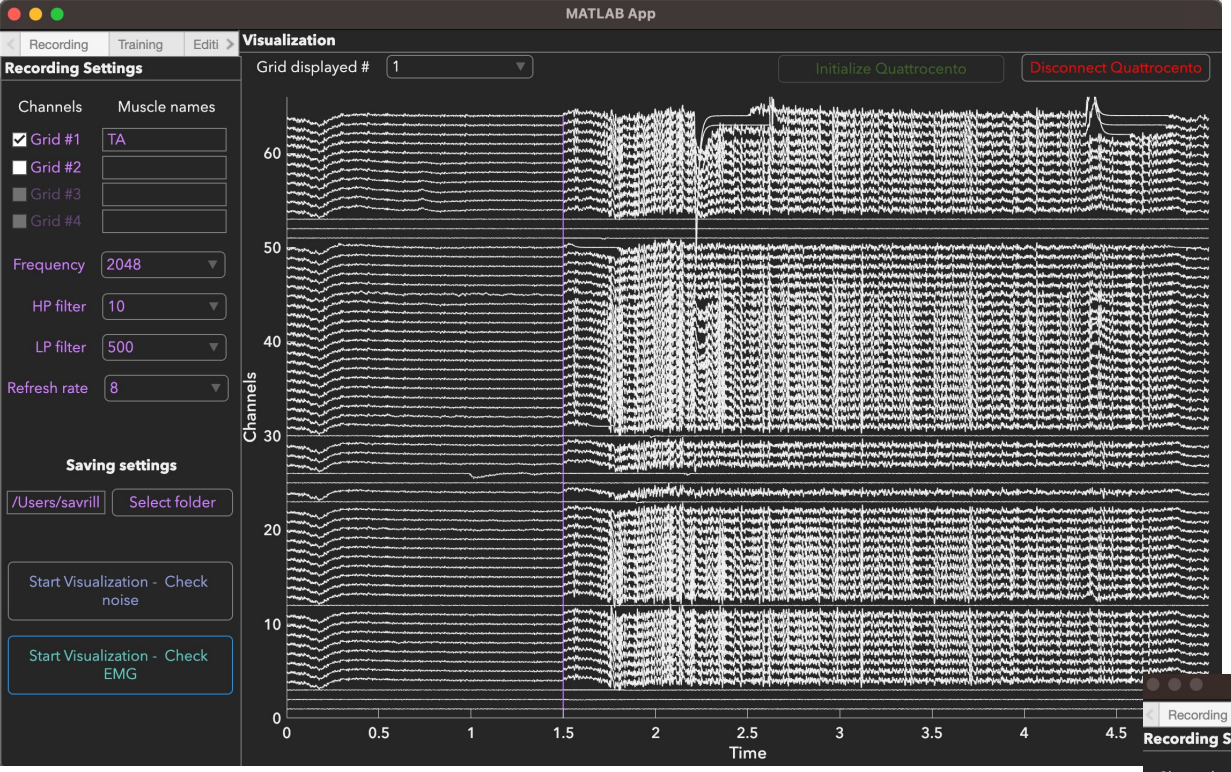
3. Edition panel



4. Bioefeedback panel

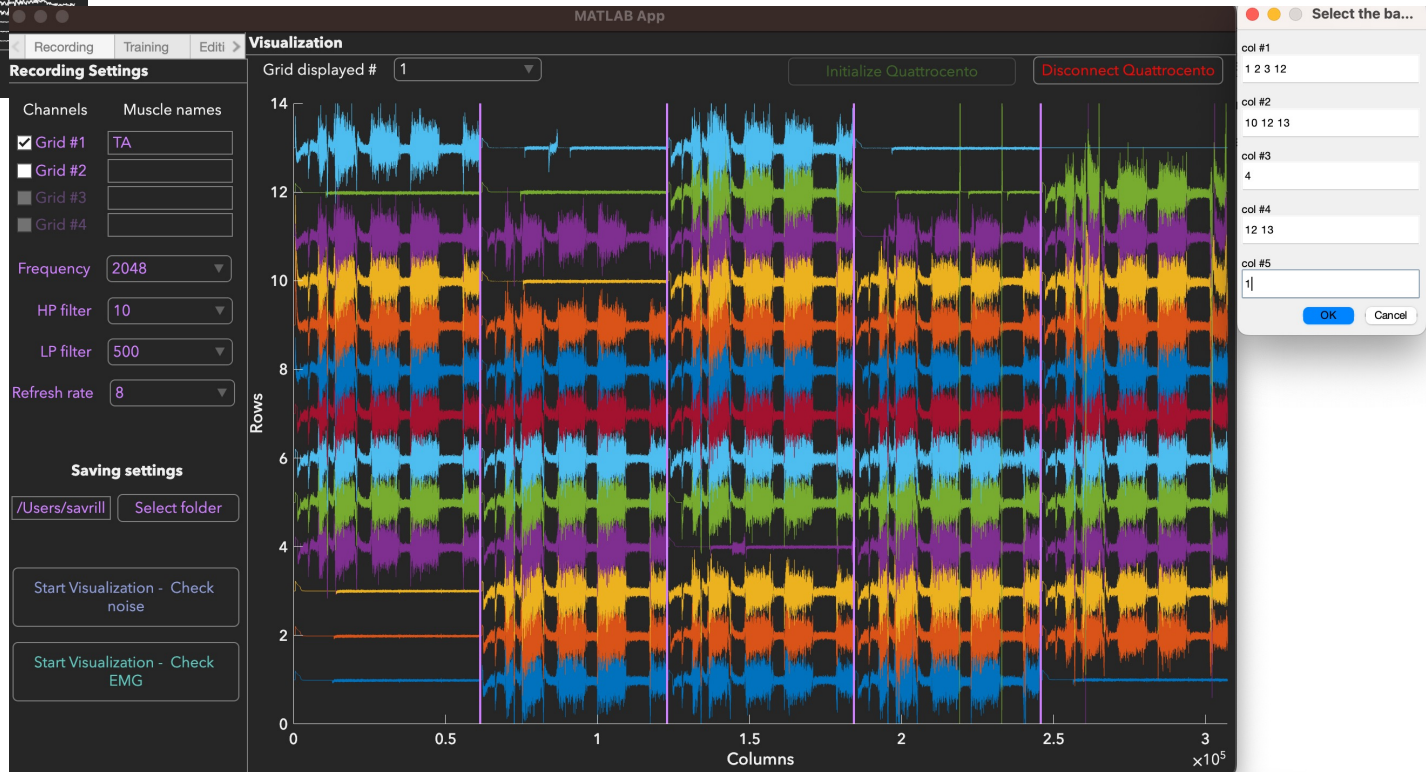



INPUTS
EMG signals from all the grids
1
Recording panel
1. Check the baseline noise
2. Identify the noisy channels
A mask for all the grids
A file with the raw EMG
EMG signals from all the grids
Force
2
Training panel
1. Remove force offset
2. Measure the MVC
3. Perform the baseline contraction
Separation 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
Bioefeedback 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)



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

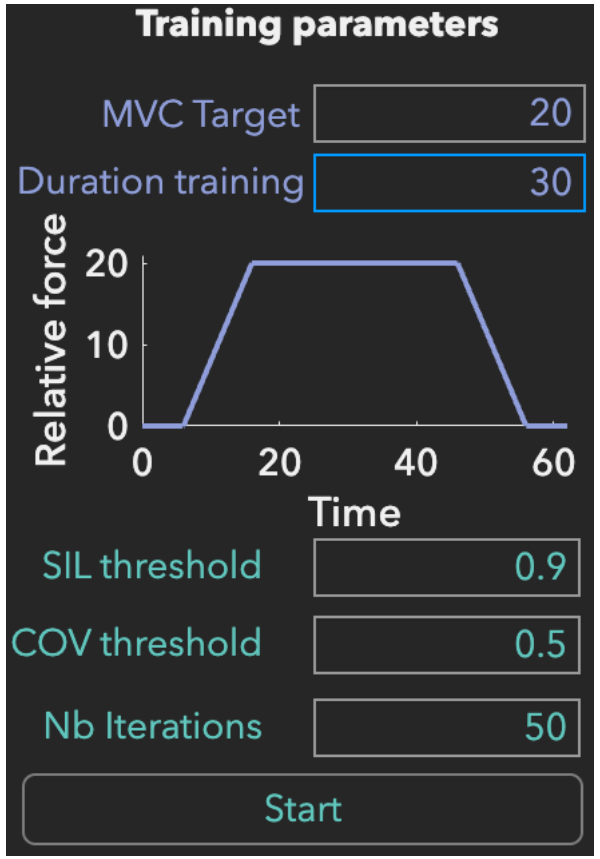
2. Check the box for recording and removing the force offset

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

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

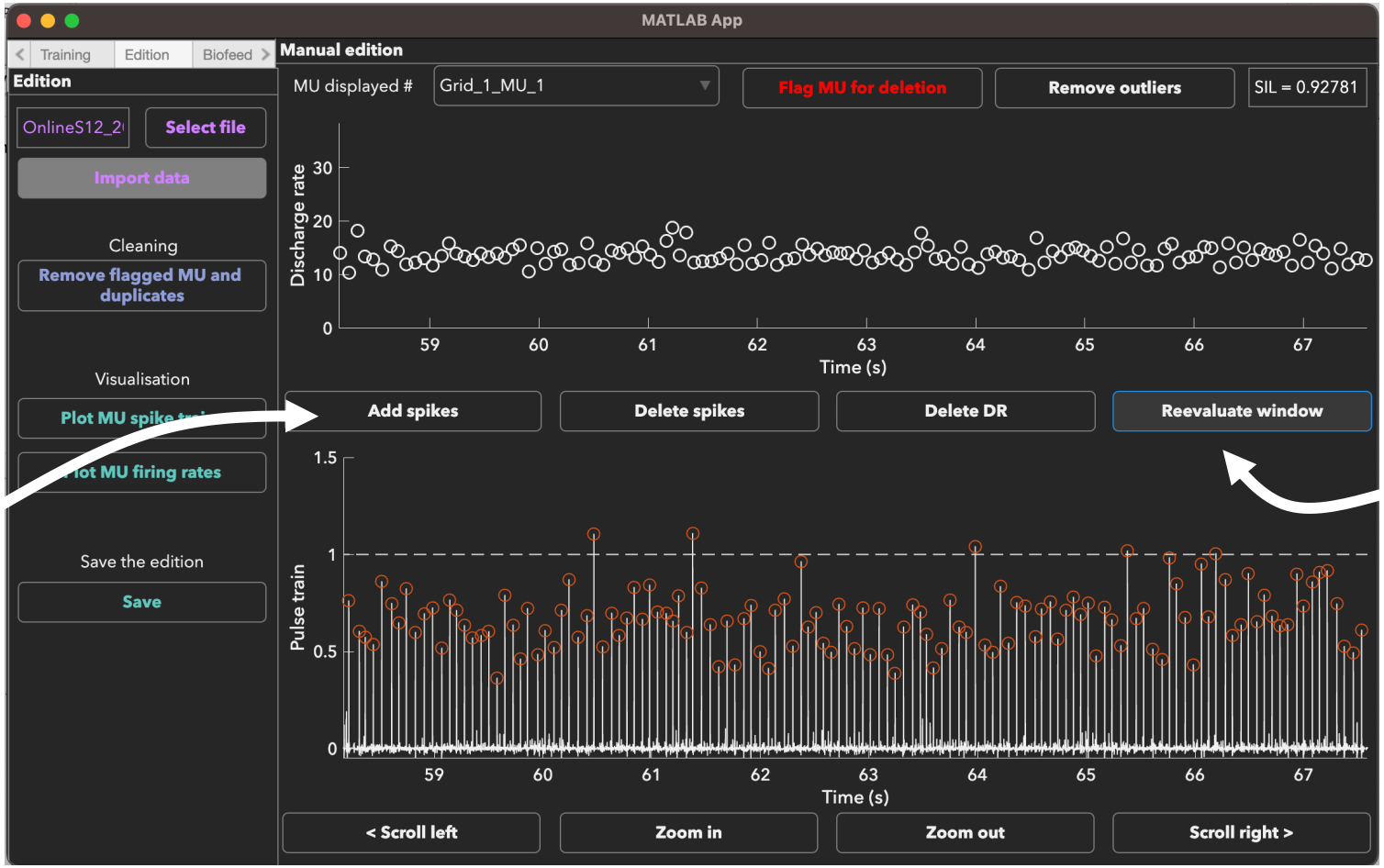
2. Set the parameters for the decomposition

- 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. Find the decomposition file and import it

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

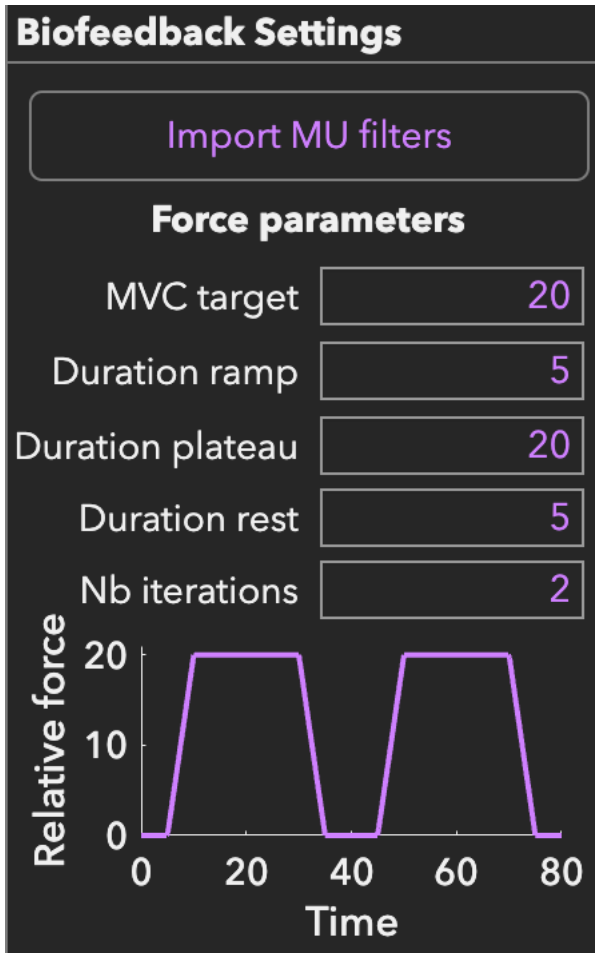


3. Manually add missing spikes or remove falsely identified artifacts

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.

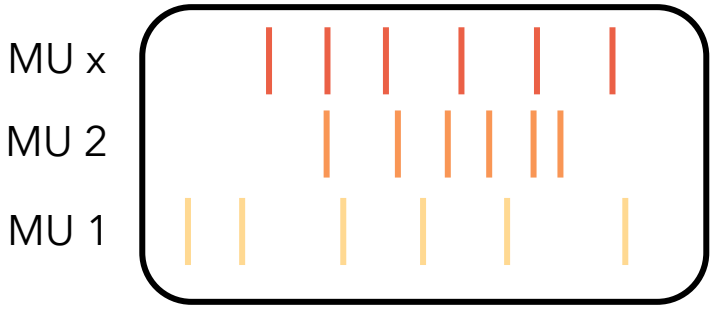
Case scenarios

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

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 plost

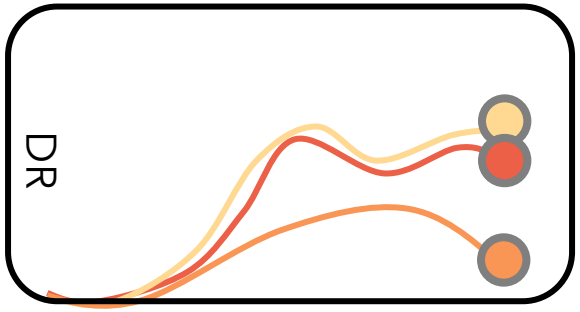


You identify all the motor units from the grid #1, e.g., the TA, and display the discharge times to the participant

Quadrant

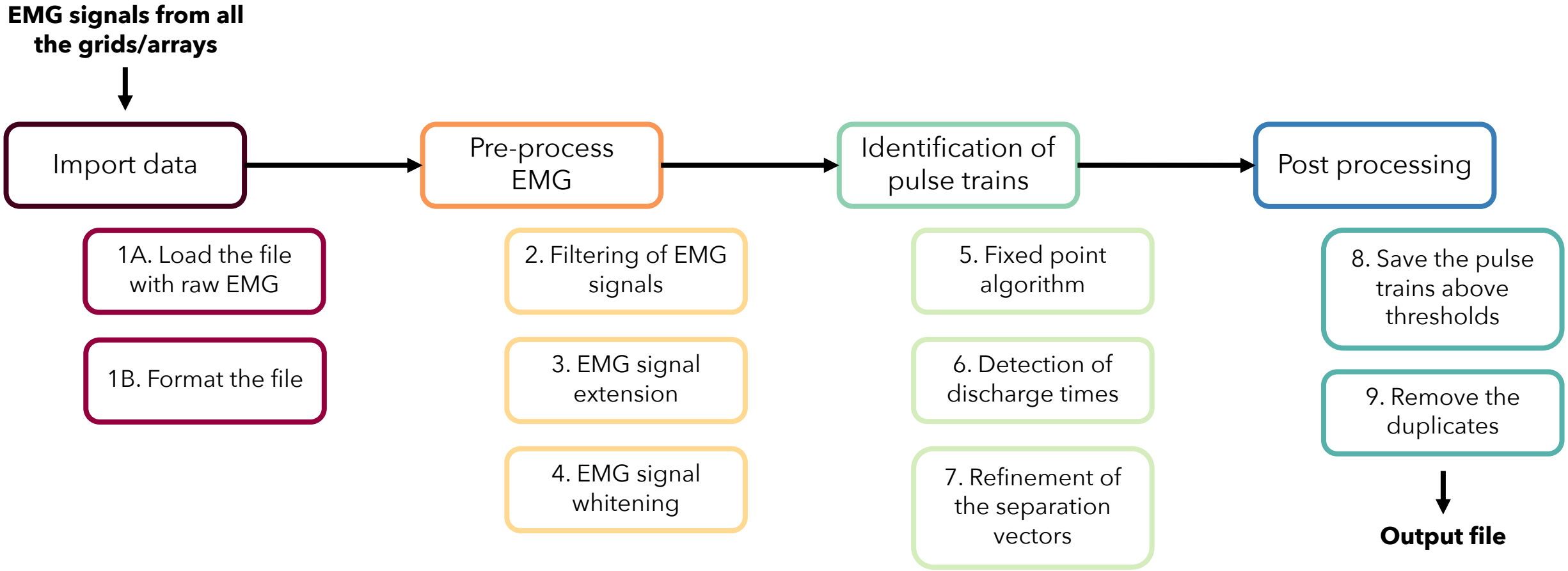
You identify one motor unit from the grid #1 and one motor unit from the grid #2. The cursor move according to their individual discharge rate

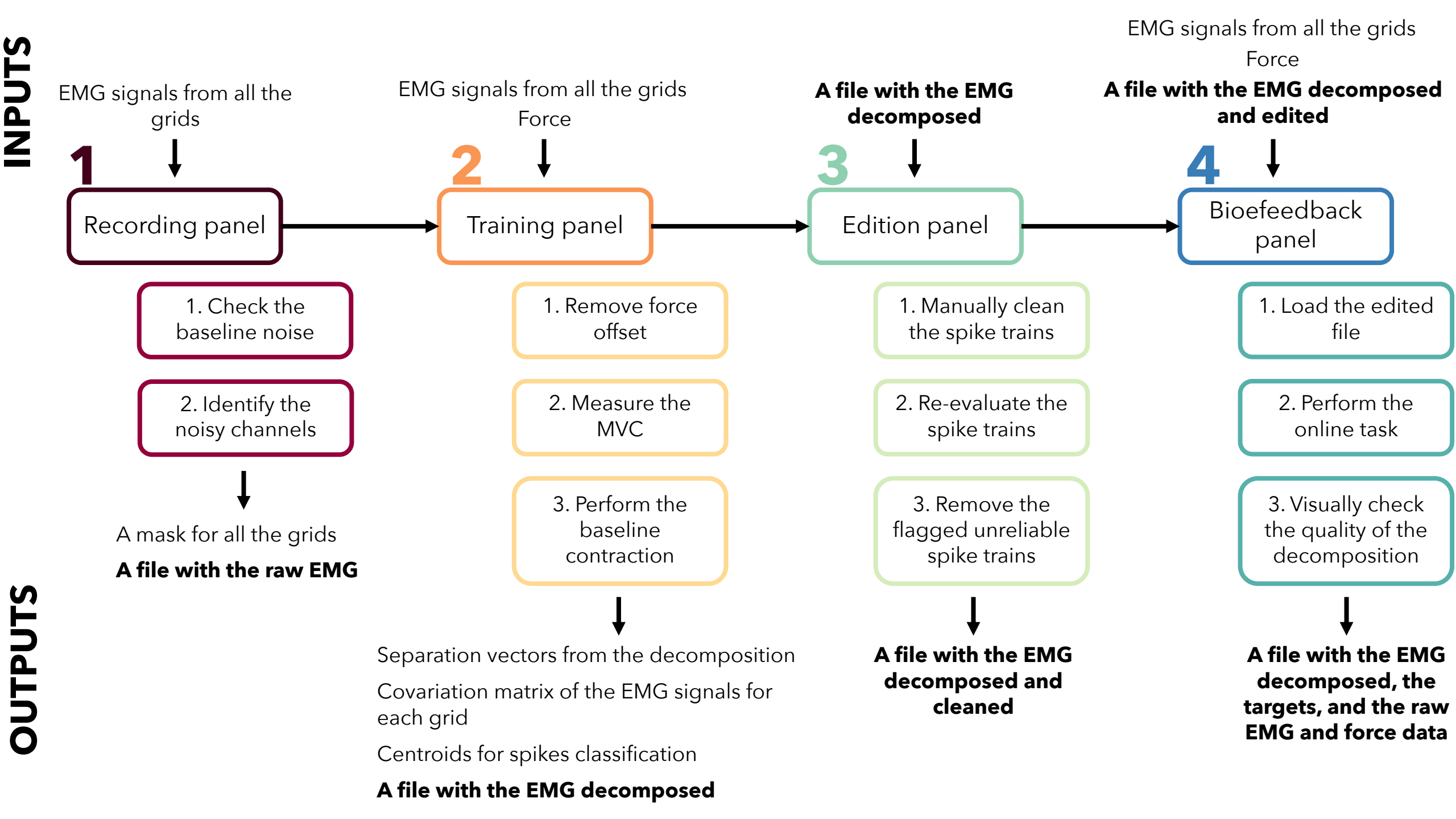
Smoothed discharge rates



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

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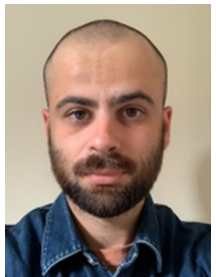
THANK YOU

Simon Avrillon



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