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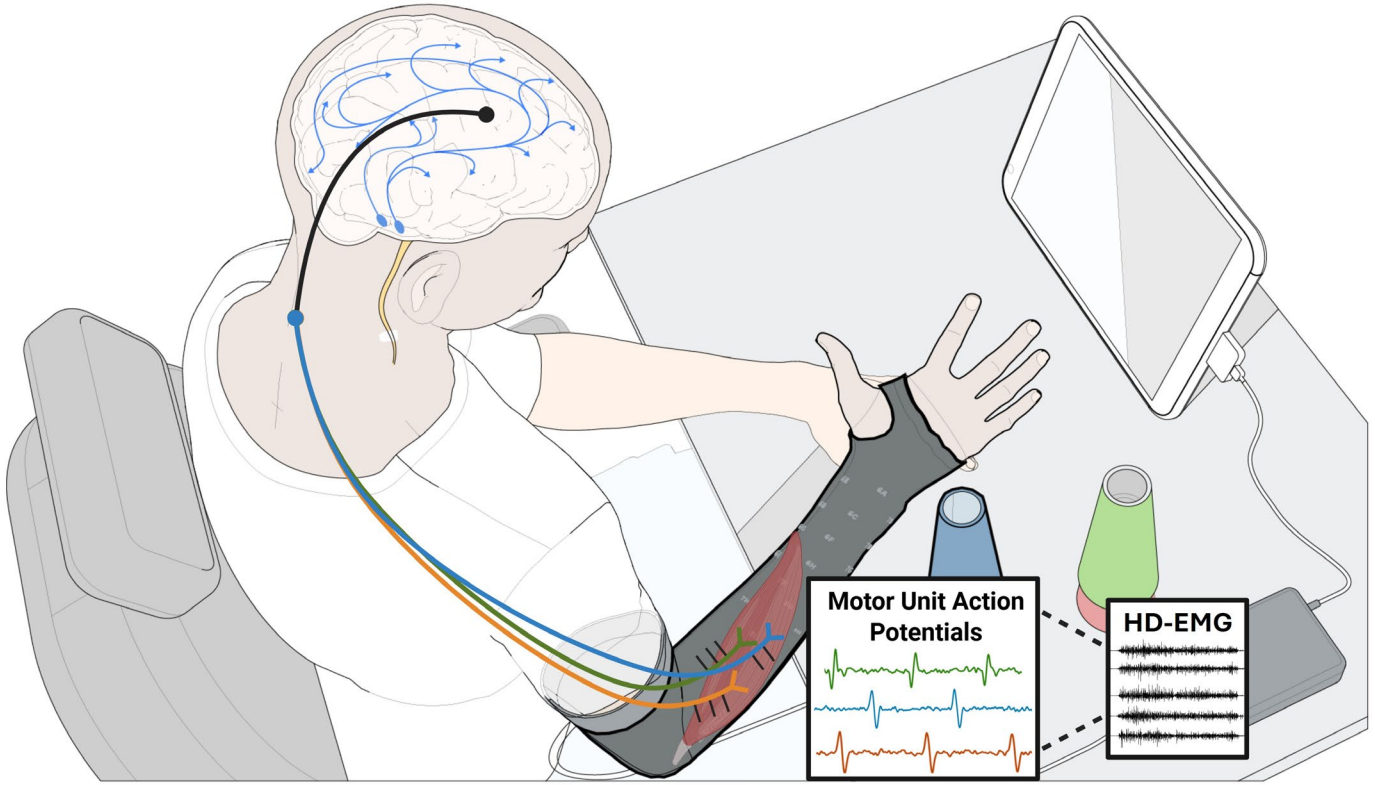
Decomposing motor units through elimination for real-time intention driven assistive neurotechnology

Motivation for motor units as a control signal

EMG decomposition as a BSS problem

Goal: Find unmixing matrix B to recover motor unit sources



$$\boldsymbol{X}(t) = \boldsymbol{H}\boldsymbol{S}(t) + \boldsymbol{N}(t)$$

$$\widehat{\boldsymbol{S}}(t) = \boldsymbol{B}\boldsymbol{X}(t)$$

$$\boldsymbol{X} \in \mathbb{R}^{C\times N} \qquad \boldsymbol{H} \in \mathbb{R}^{C\times M} \qquad \boldsymbol{S} \in \mathbb{R}^{\mathrm{M}\times N}$$

C: number of EMG channels
N: number of samples in time
M: number of motor unit sources

MUelim algorithm

Input EMG data $\boldsymbol{X}$ is first divided into non-overlapping windows followed by an extend-lag procedure to incorporate temporal information

$$\boldsymbol{X_{ext}}(t) = [\boldsymbol{X_{binned}}(t), \boldsymbol{X_{binned}}(t-\tau), \ldots, \boldsymbol{X_{binned}}(t-(R-1)\tau)]^{\top}$$

$\boldsymbol{X_{binned}} \in \mathbb{R}^{W \times C \times L}$

$\boldsymbol{X_{ext}} \in \mathbb{R}^{W \times CR \times L}$

W: number of windows
L: size of window
R: extension factor
τ: lag

SPD matrix computation on $\boldsymbol{X_{ext}}$ and whitening

$$\boldsymbol{C_f} = \frac{1}{W}\sum_{k=1}^{W} \boldsymbol{X'_{ext,f}}[k]\boldsymbol{X'_{ext,f}}[k]^{H}$$

$$\boldsymbol{W_{whiten}} = \boldsymbol{V\Lambda^{-1/2}V^{T}}, \quad \boldsymbol{C_f^{whiten}} = \boldsymbol{W_{whiten}C_fW_{whiten}^{T}}$$

Approximate joint diagonalization

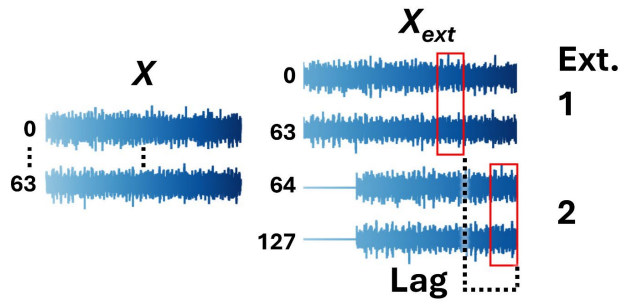
$$\mathcal{L}(\boldsymbol{B}) = \frac{1}{2n}\sum_{i=1}^{n}[\log\det diag\,(\boldsymbol{BC_iB}^{\top}) - \log\det(\boldsymbol{BC_iB}^{\top})]$$

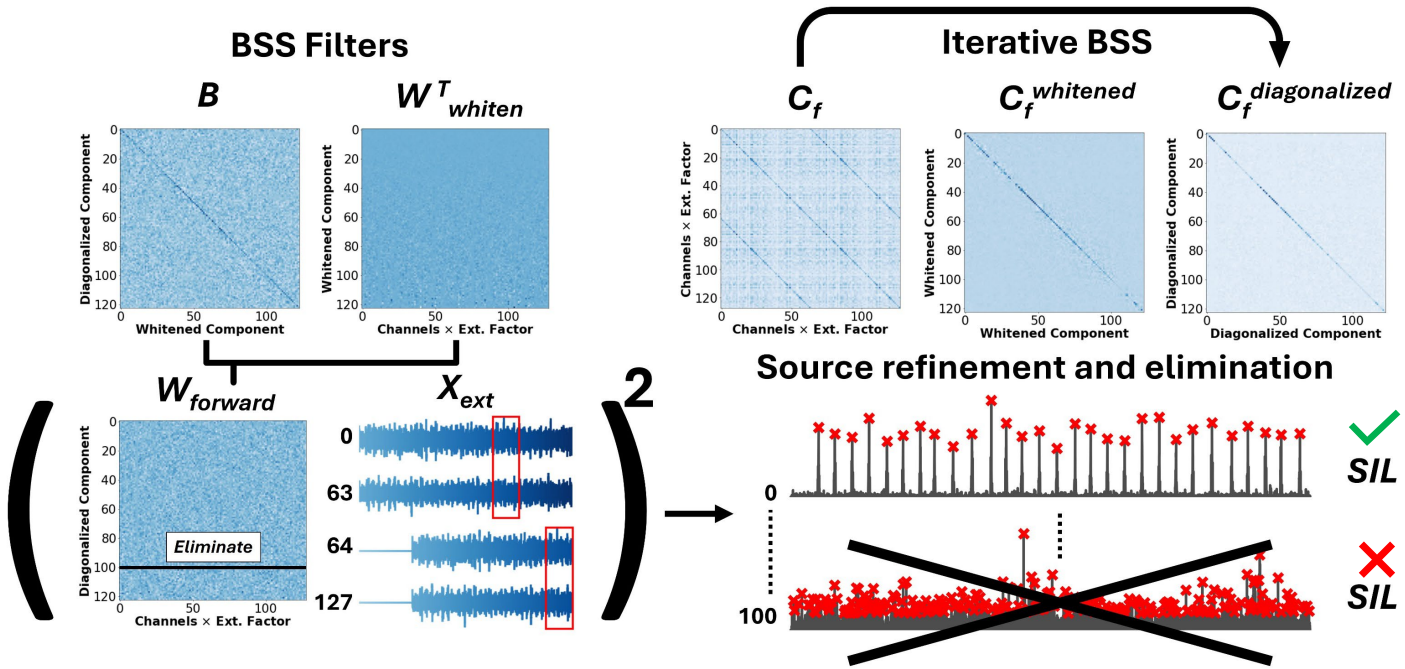
$$\boldsymbol{W_{forward}} = \boldsymbol{BW_{whiten}^{\top}}$$

Improvement iteration and elimination

$$\boldsymbol{\gamma_j}(k) = \left(\boldsymbol{W_{forward}X_{ext}}\right)^{2}$$

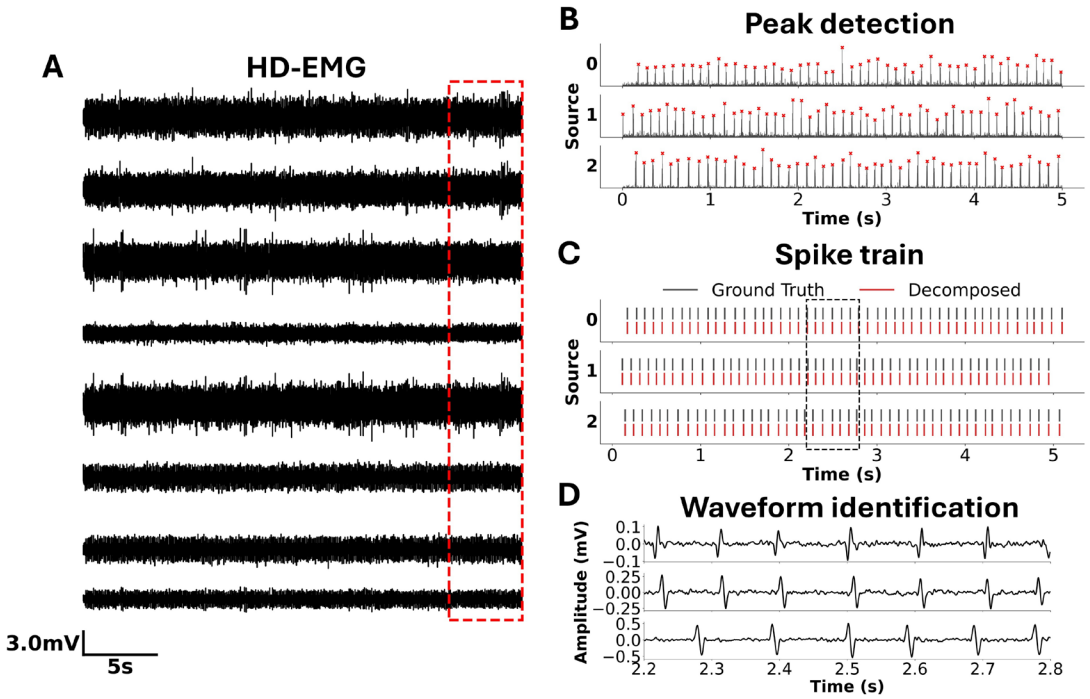
MUelim algorithm overview





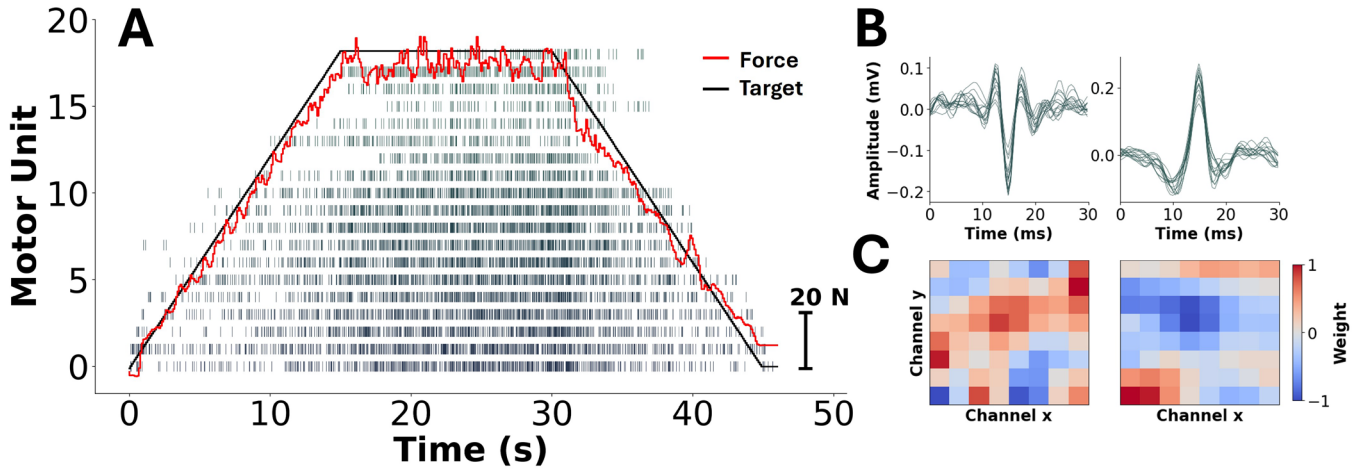
Algorithm evaluation

Simulation Experiments



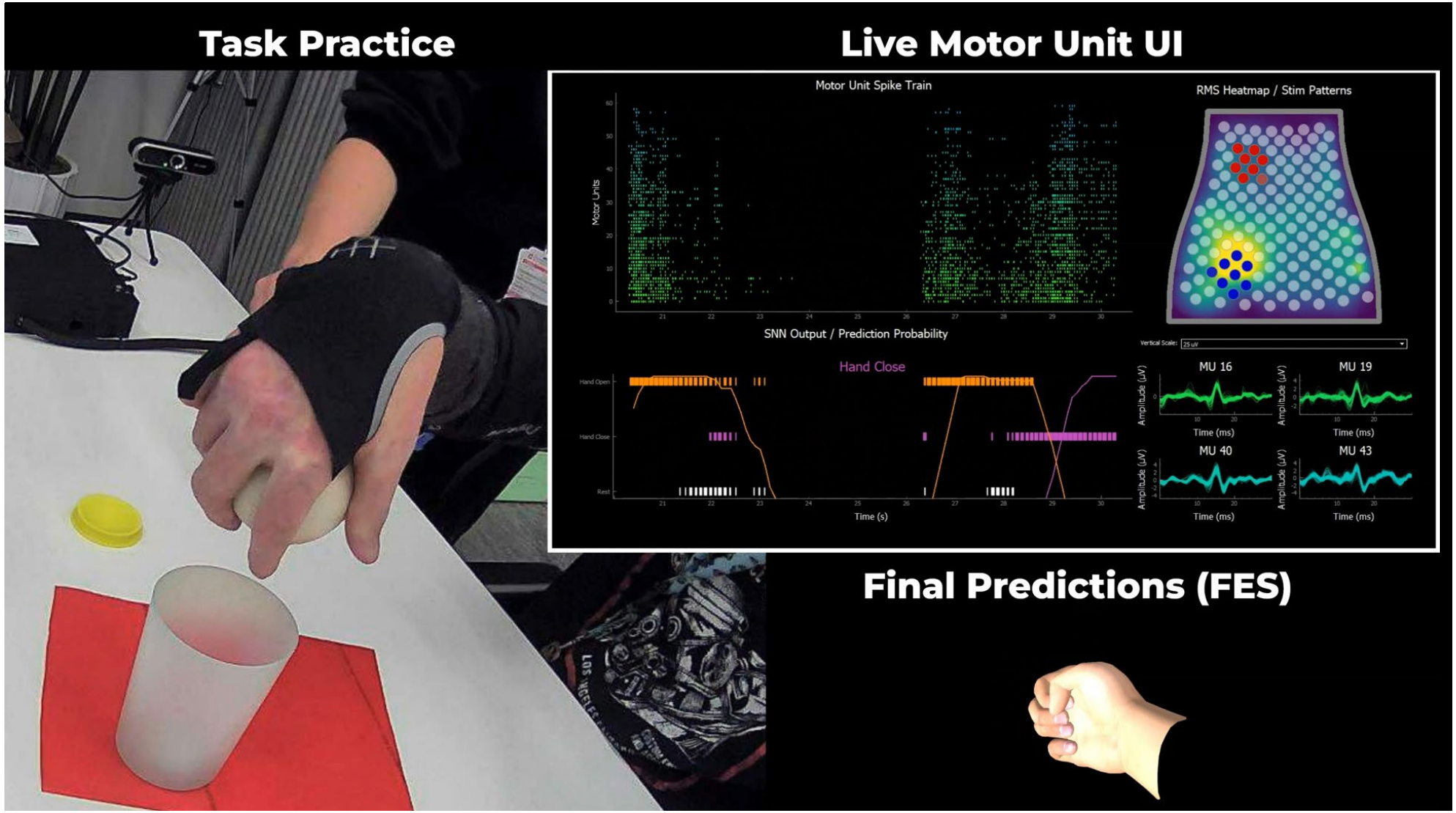
Method	Accuracy (%)	FP per source	FN per source
MUelim	99.99 ± 0.01	0.99 ± 0.14	0.03 ± 0.02
SCD	99.99 ± 0.01	0.93 ± 0.13	0.03 ± 0.02
MUEdit	98.98 ± 0.07	0.00 ± 0.00	3.06 ± 0.20

HD-EMG Grid Experiments



Method	Ext.	Lag	Ramp Experiment			MVC Experiment		
			MUs	Time (min.)	SIL	MUs	Time (min.)	SIL
MUelim	2	4	12.8 ± 2.7	1.3 ± 0.1	0.91 ± 0.01	7.8 ± 1.8	0.3 ± 0.0	0.91 ± 0.01
	4	4	18.8 ± 4.2	3.1 ± 0.2	0.92 ± 0.01	11.2 ± 2.2	0.7 ± 0.0	0.91 ± 0.01
SCD	6	1	2.4 ± 0.5	5.5 ± 0.6	0.89 ± 0.01	5.6 ± 1.4	9.2 ± 3.0	0.90 ± 0.02
	16	1	3.2 ± 0.8	14.6 ± 3.6	0.90 ± 0.01	5.6 ± 1.7	5.7 ± 1.1	0.90 ± 0.01
MUEdit	6	1	3.2 ± 2.0	72.3 ± 4.5	0.88 ± 0.01	24.3 ± 9.6	10.9 ± 2.2	0.89 ± 0.00
	16	1	18.2 ± 5.7	112.3 ± 28.5	0.89 ± 0.03	12.5 ± 3.2	30.9 ± 5.5	0.93 ± 0.01

Closed-loop FES for spinal cord injury



Acknowledgments

Battelle Neurotechnology Team

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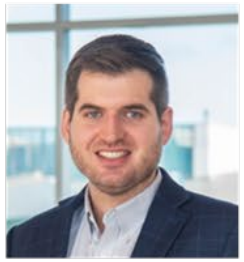

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