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HYBRID NEURO

Motor unit behaviour in voluntary and evoked contractions

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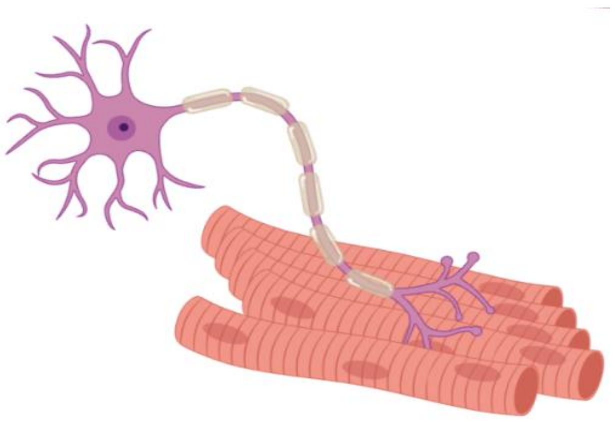
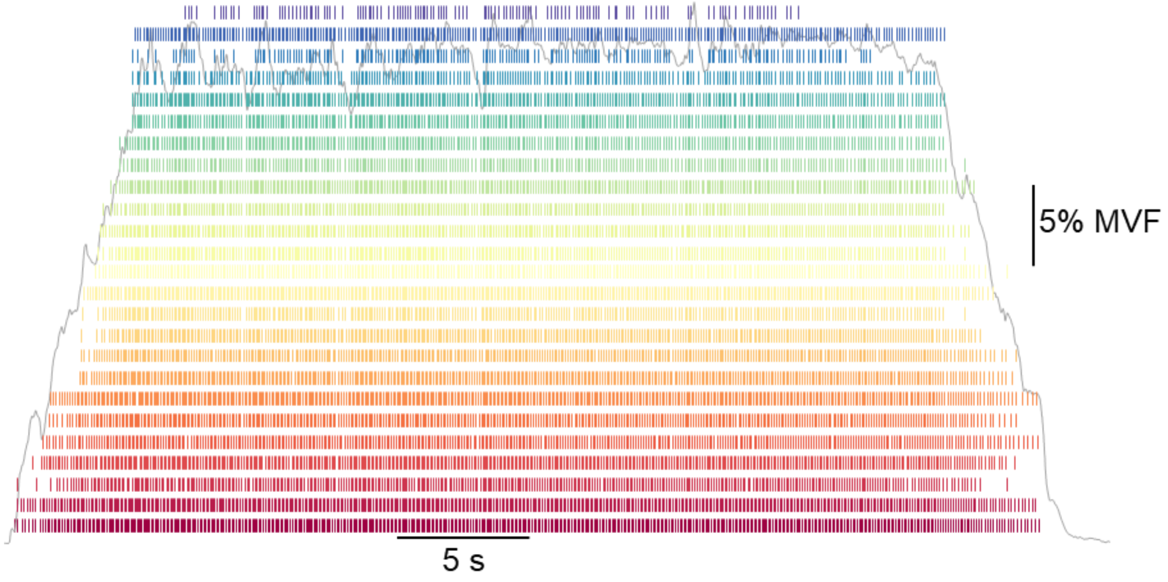
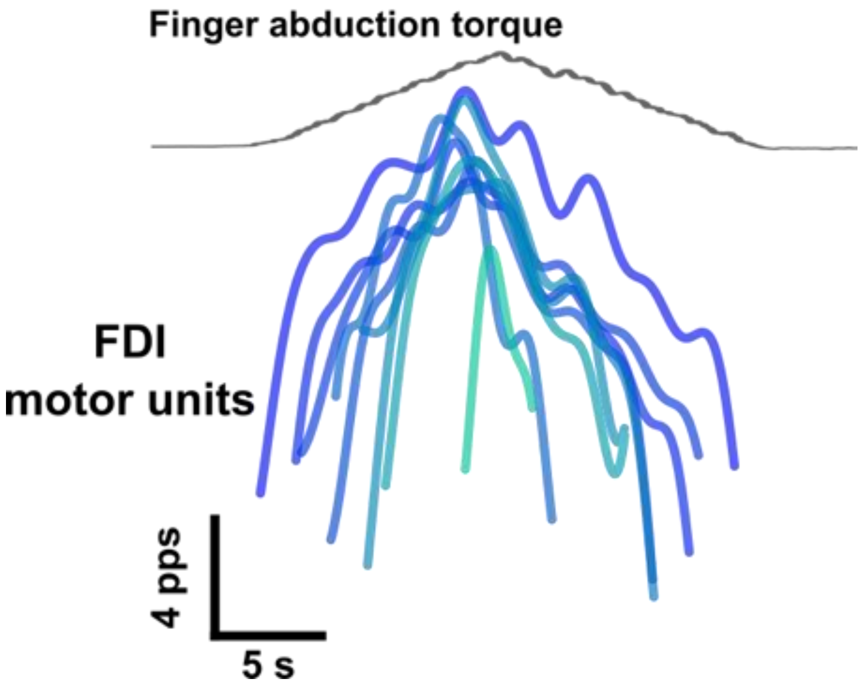
Versus Arthritis

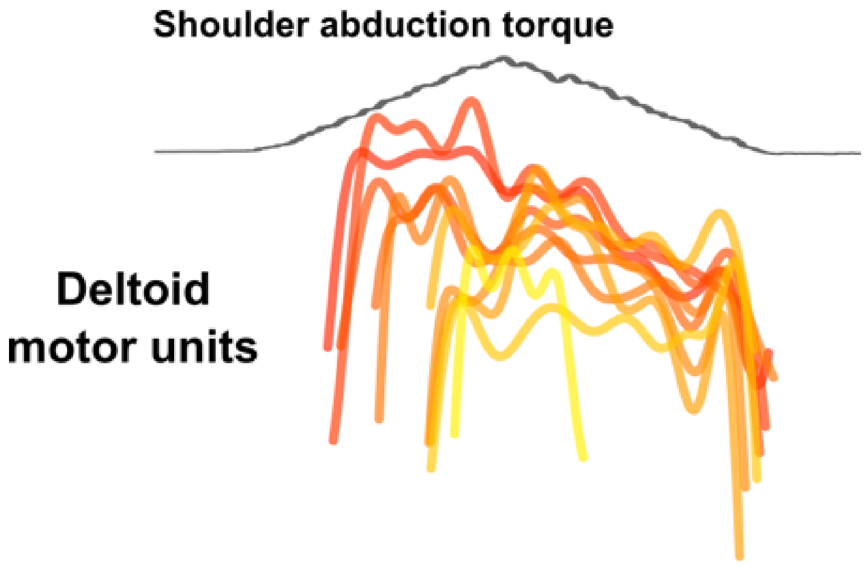
NRC
Turning Adversity into Opportunity



“Final common pathway”
(Sherrington, 1925)





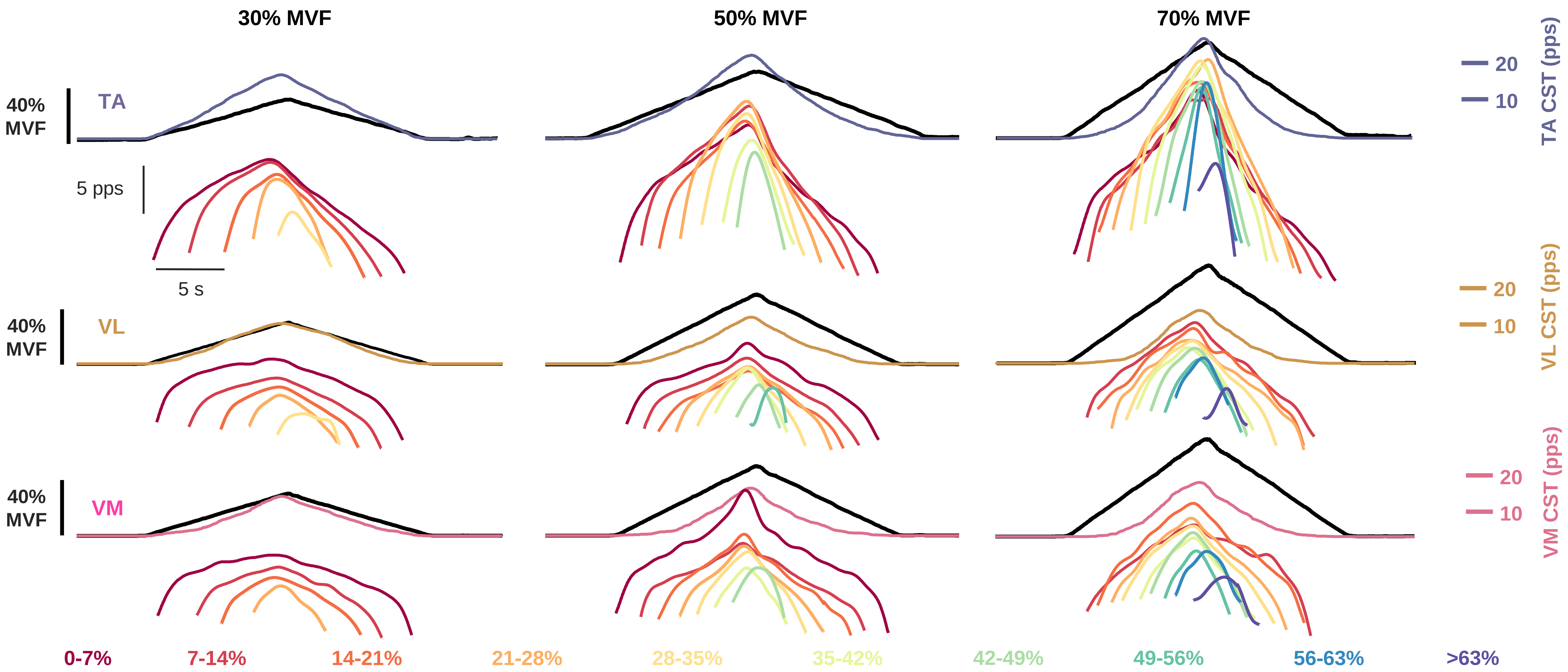


Figures courtesy of Dr Pearcey (Memorial, CAN / Northwestern, US)

PART 1

- Considerations when quantifying motor unit discharge rate during voluntary (isometric) contractions
- Different types of inputs and their effect on motor unit discharge behaviour
- Quantification of motor unit discharge behaviour in different conditions and populations

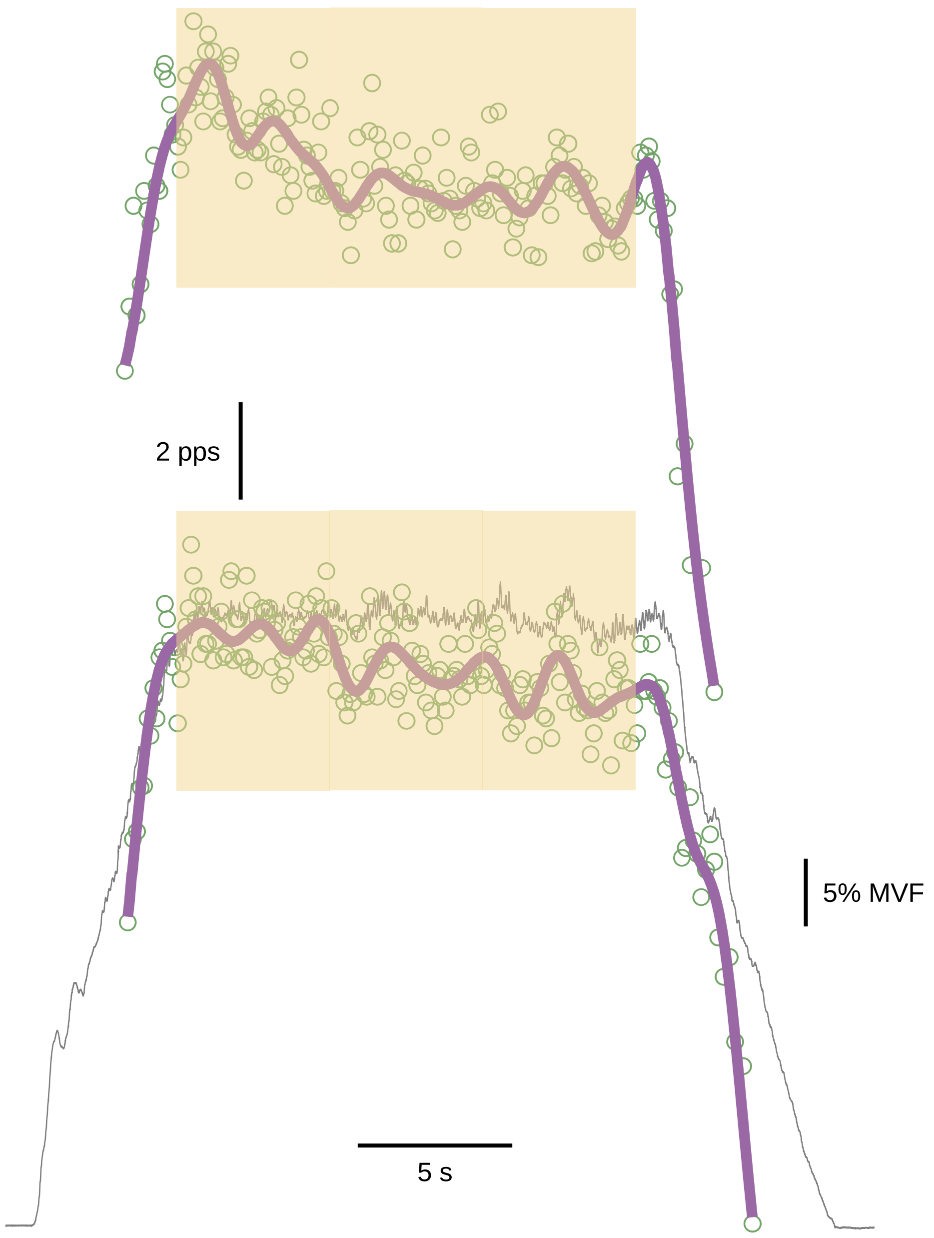
The relationship between motor unit recruitment threshold and firing rate

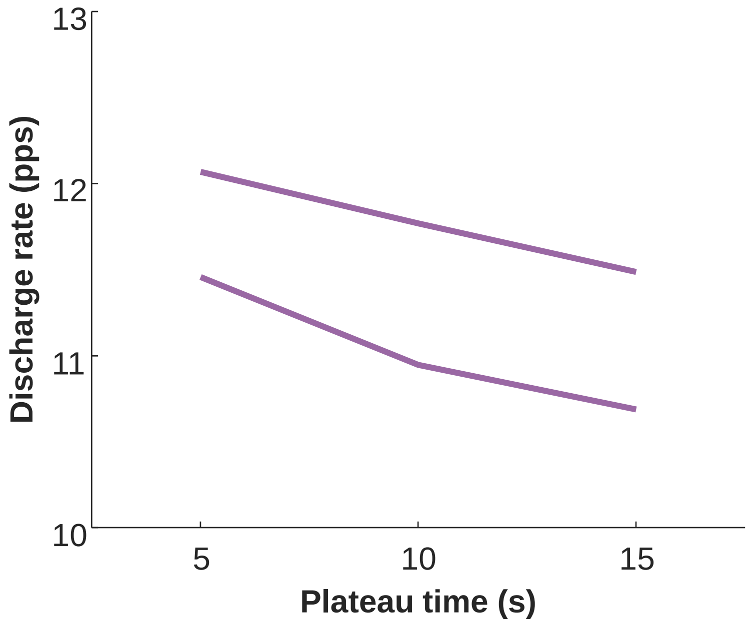


Discharge rate ~ 1 + Contraction*Muscle + Recruitment threshold + (1 | PID)

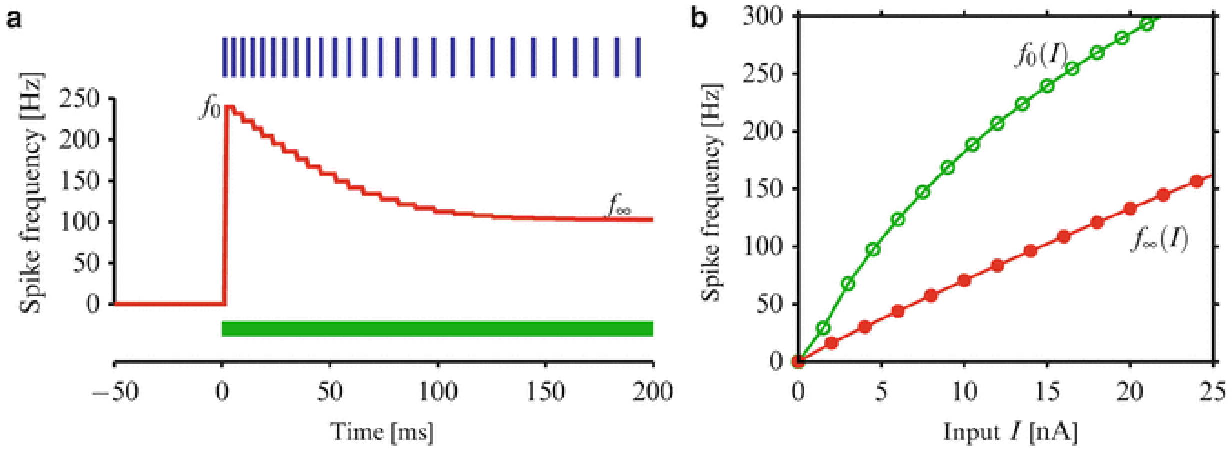
Škarabot et al. 2023, *bioRxiv*

Quantifying motor unit discharge rate



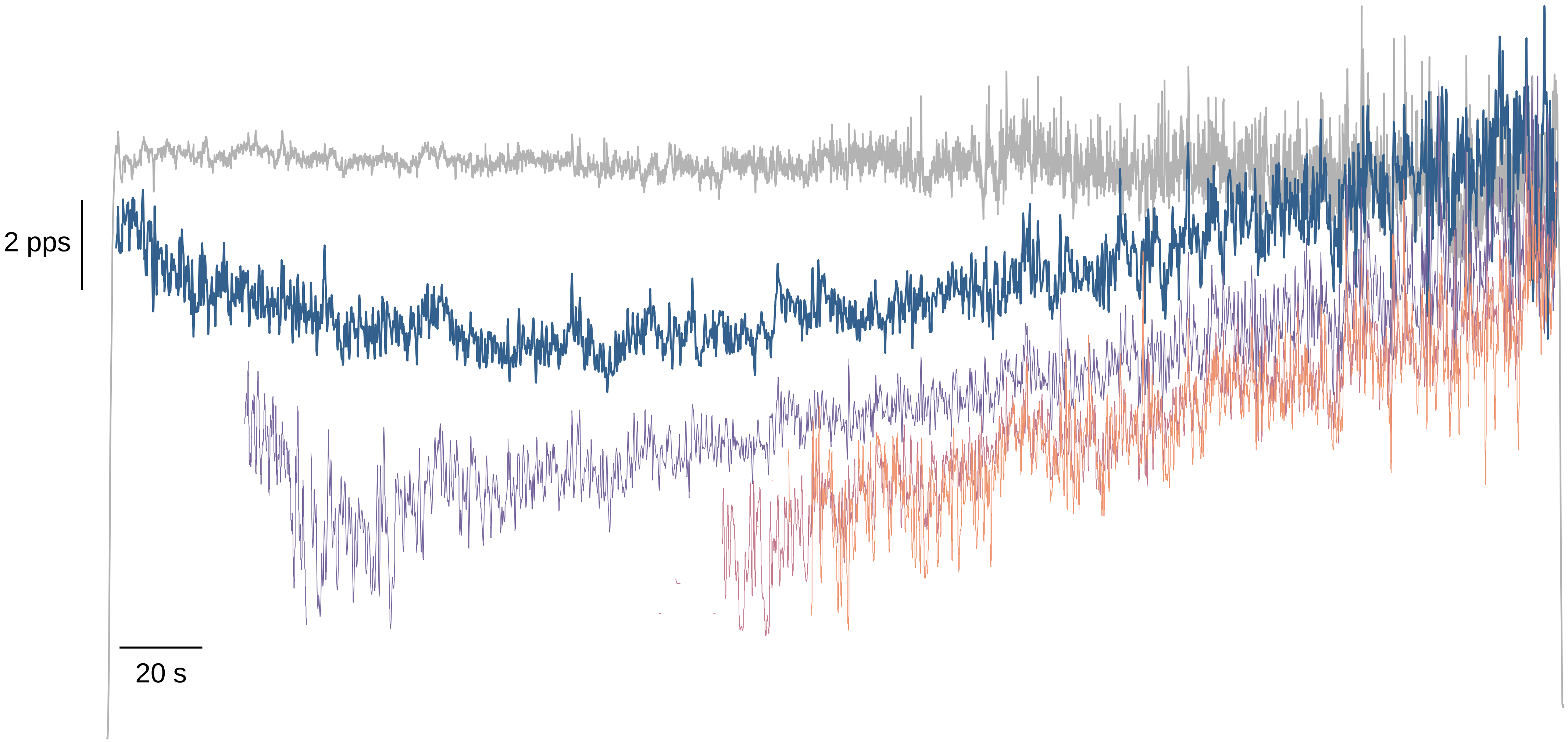


Spike frequency adaptation

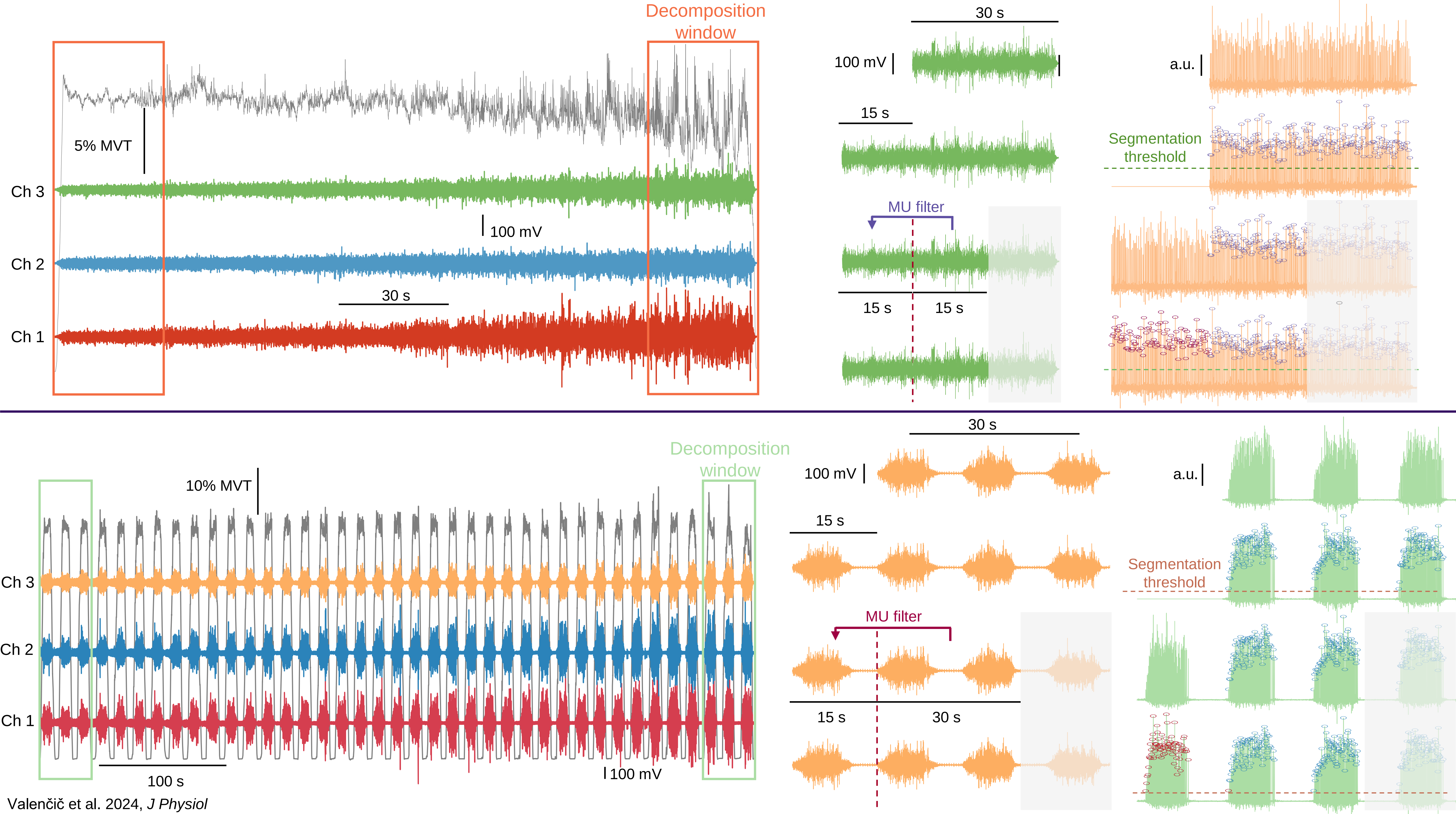


Jaeger & Jung 2020, *Enc Comp Neurosci*

Quantifying motor unit discharge rate

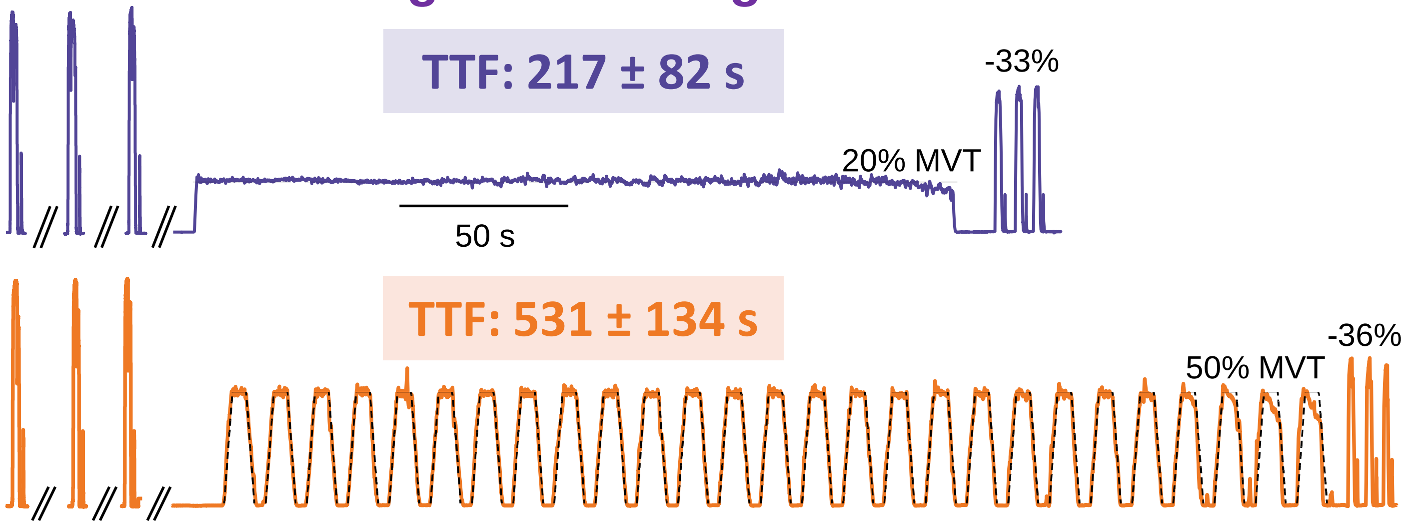


Valenčič et al. 2024, *J Physiol*



Valenčič et al. 2024, *J Physiol*

Motor unit discharge rate during contractions to failure



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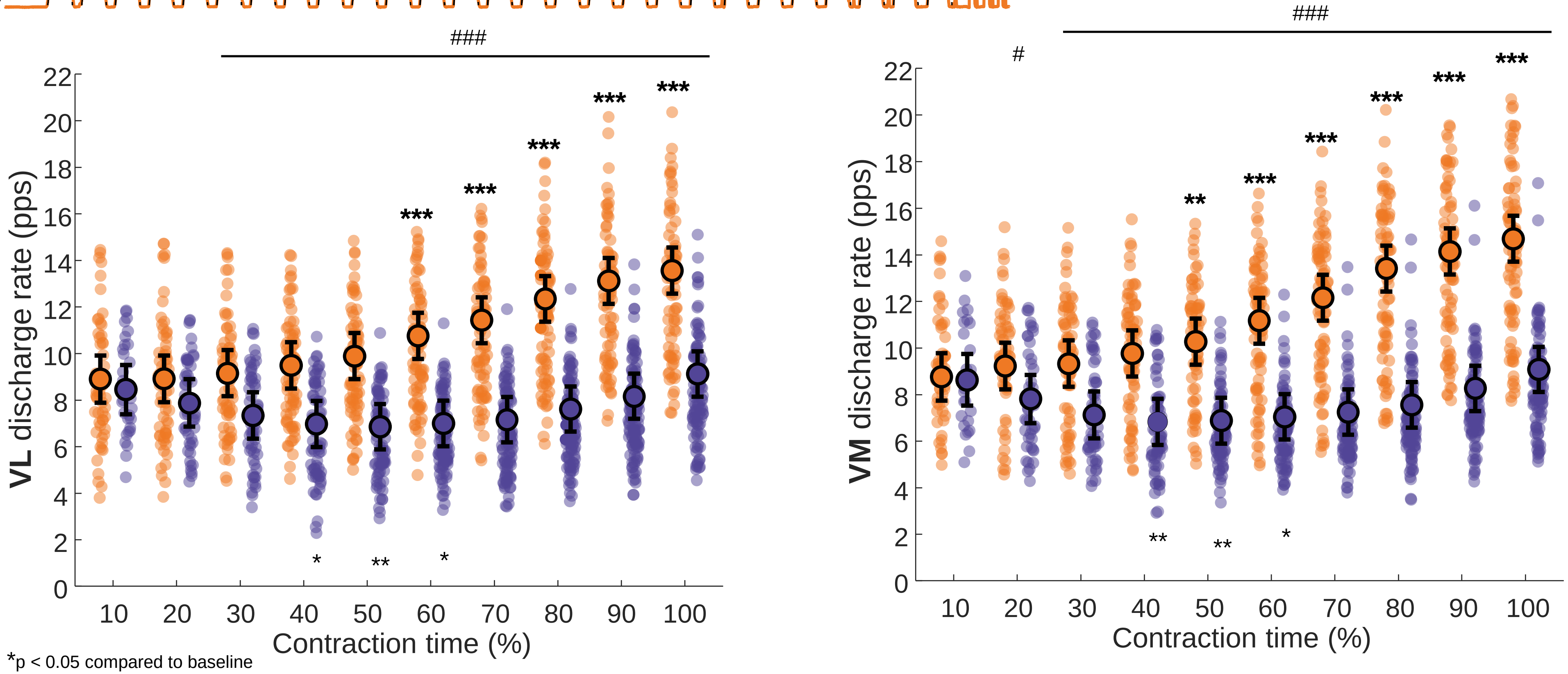
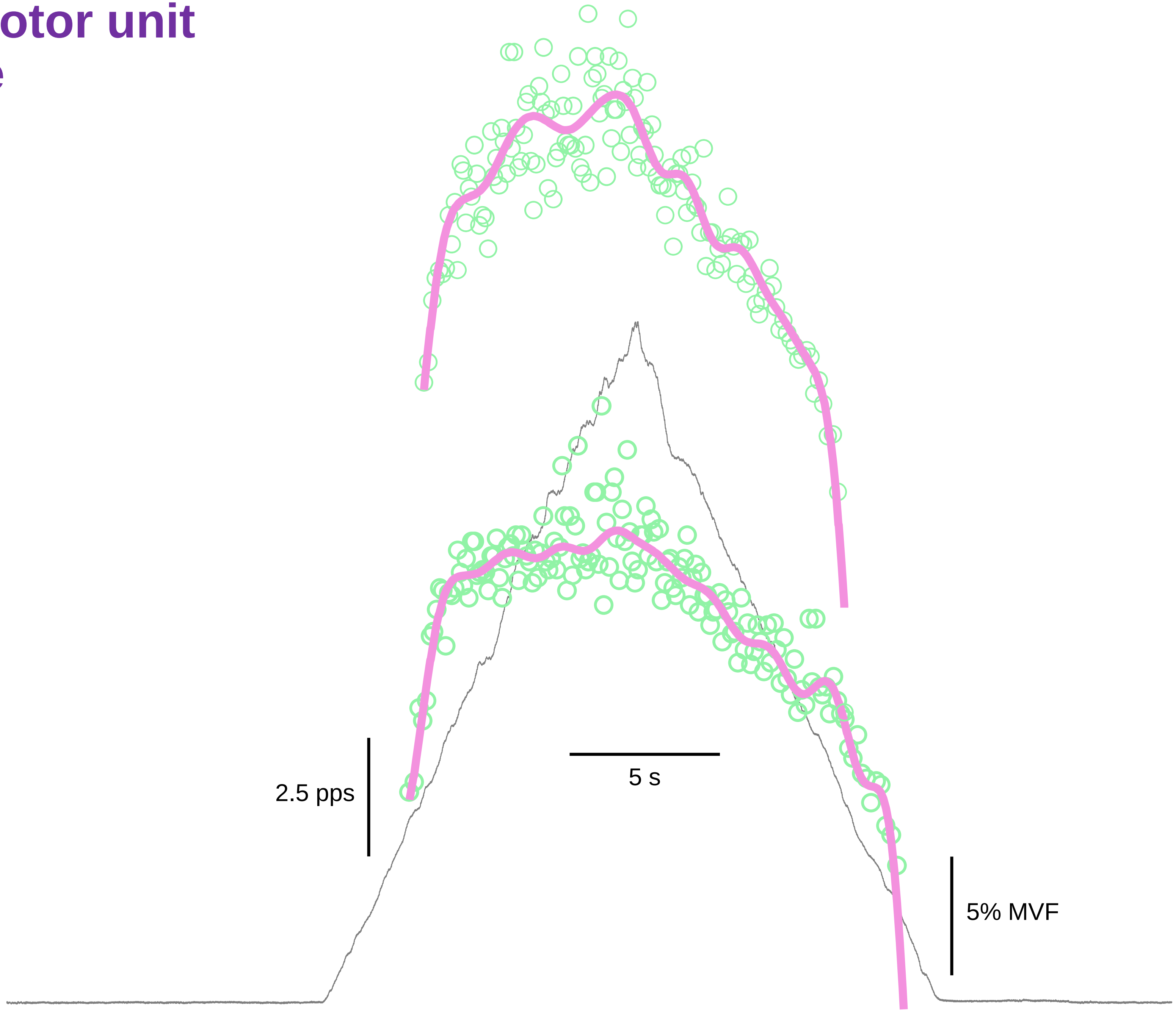


***p < 0.001, **p < 0.01, *p < 0.05 compared to baseline

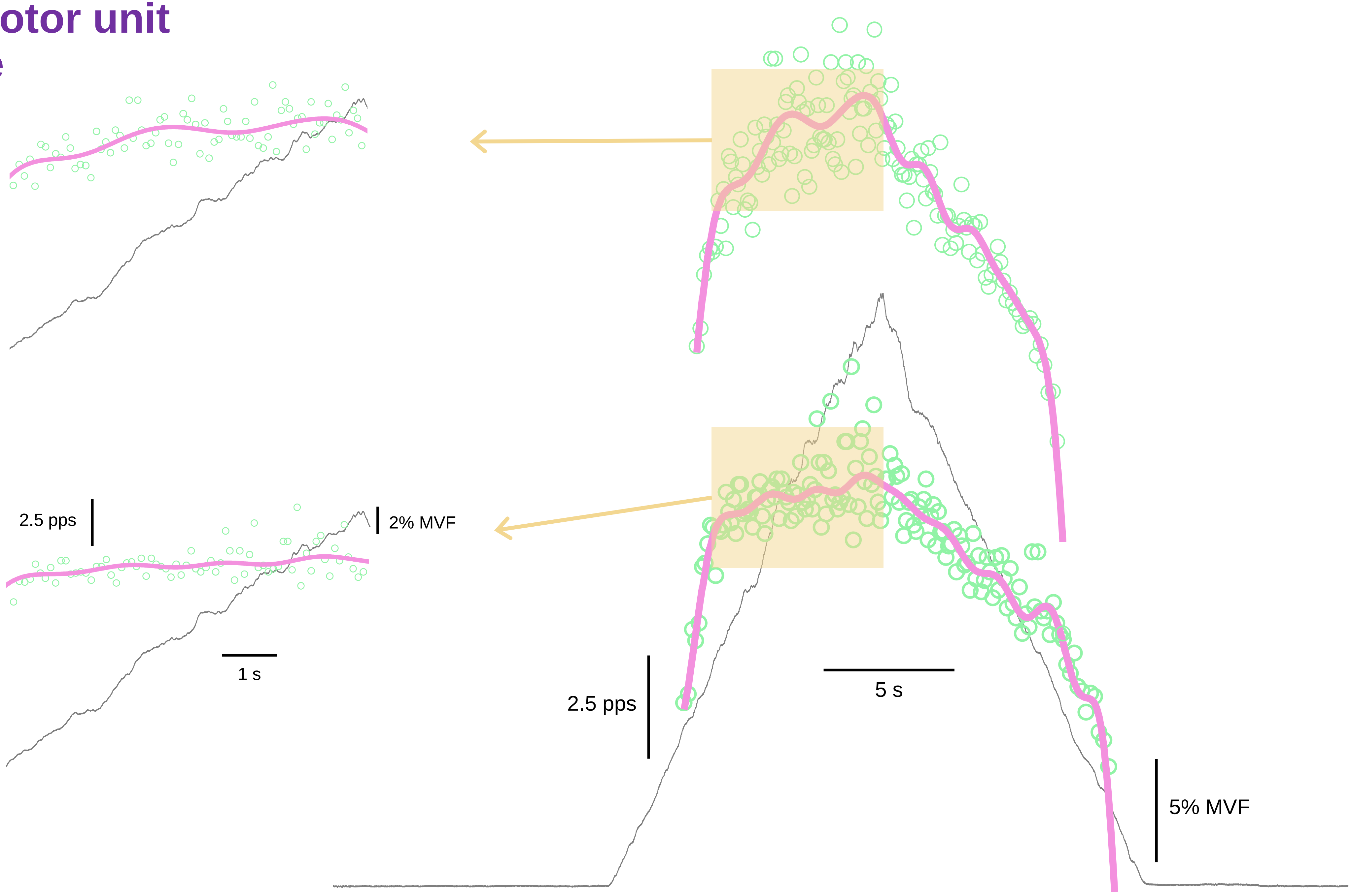
###p < 0.001, ##p < 0.01, #p < 0.05 compared to the other task

Valenčič et al. 2024, *J Physiol*

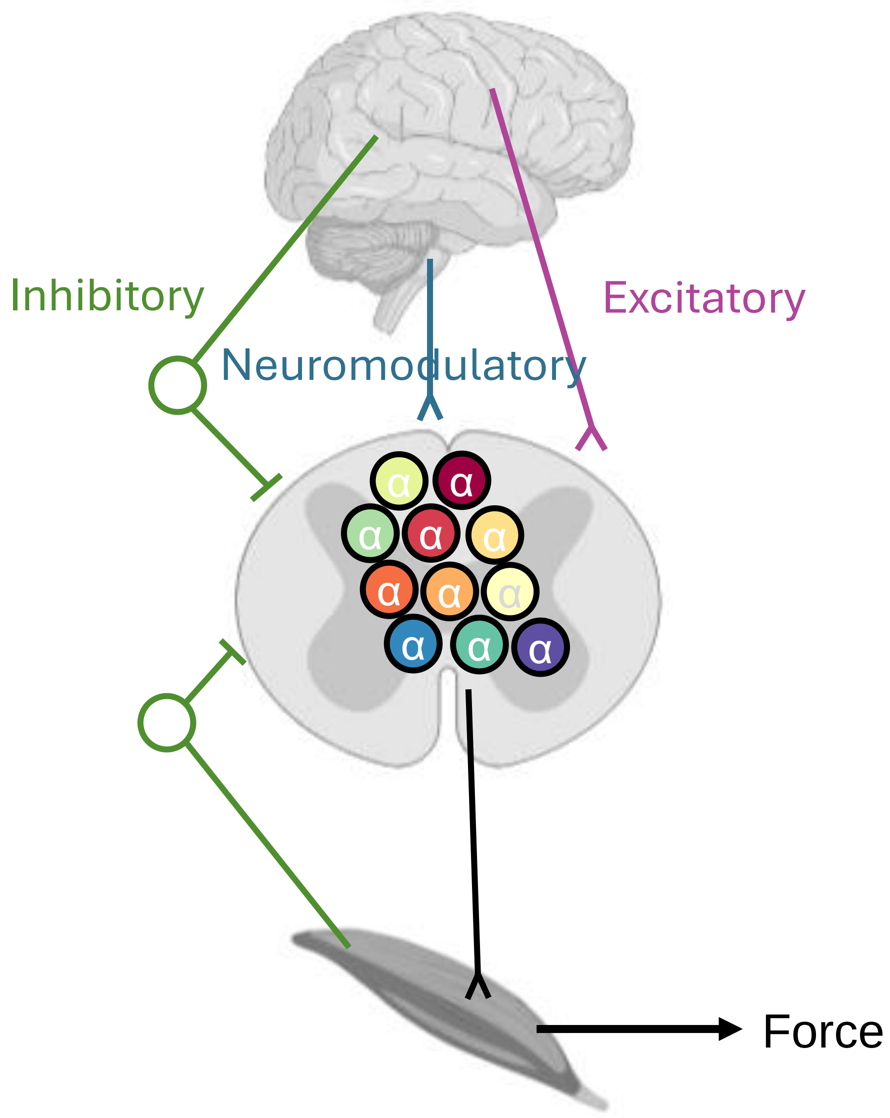
Quantifying motor unit discharge rate

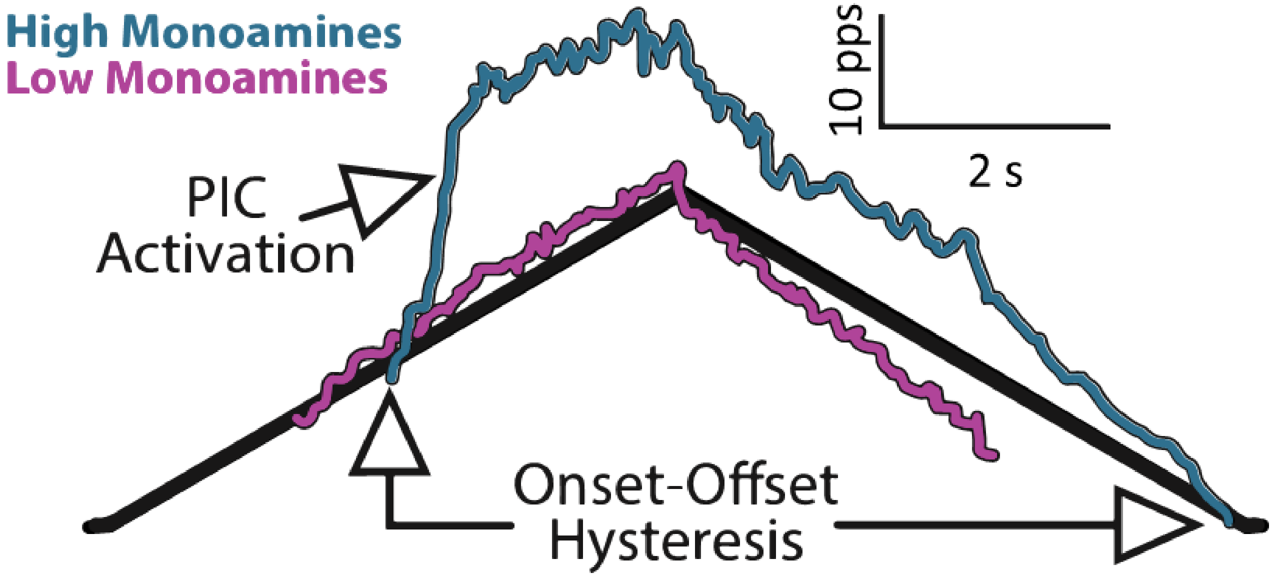


Quantifying motor unit discharge rate



Different types of inputs to motoneurons

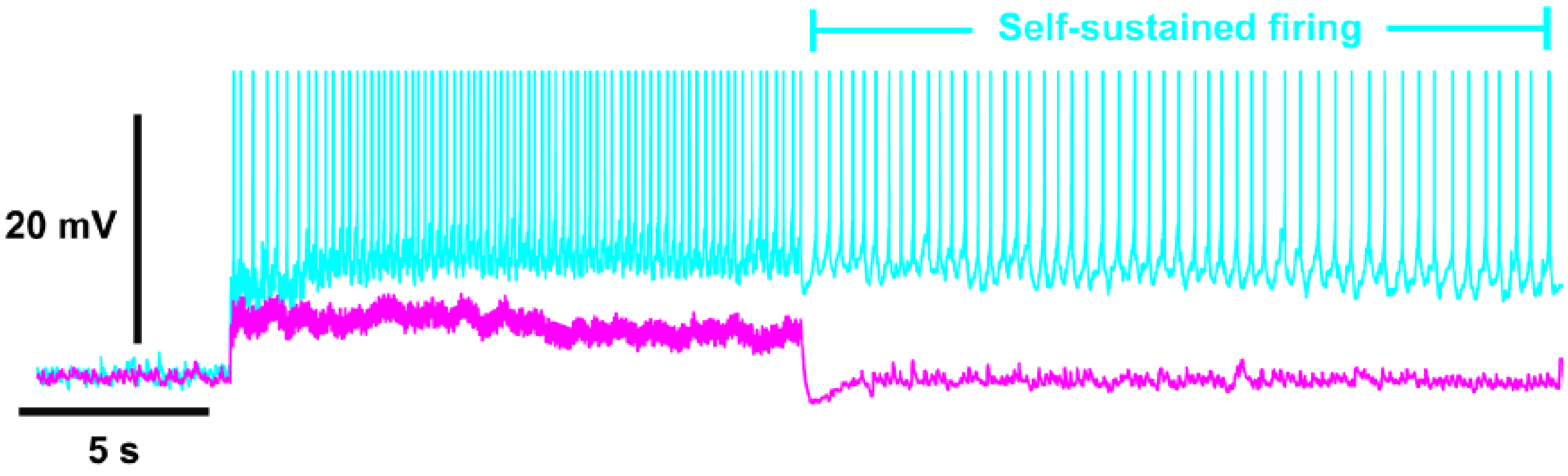


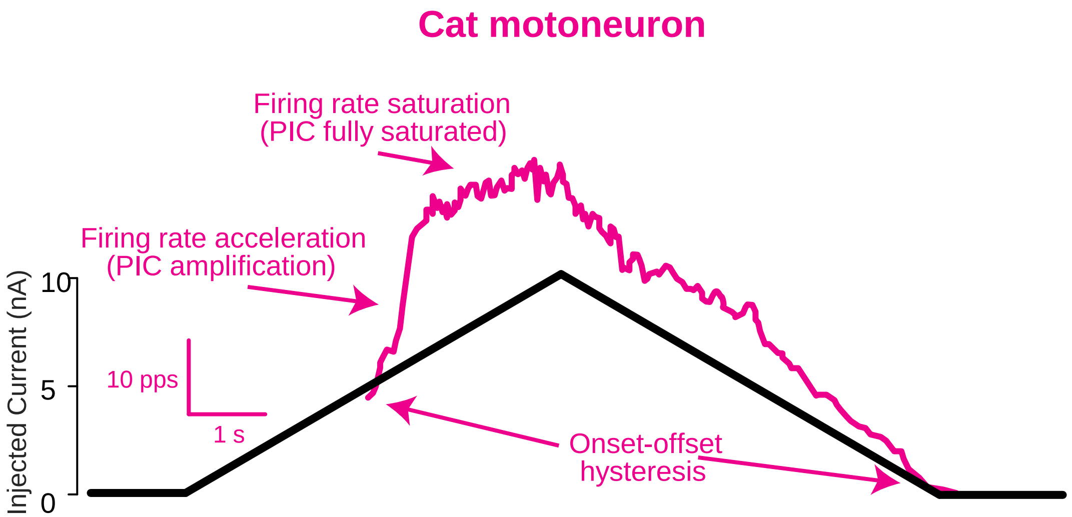


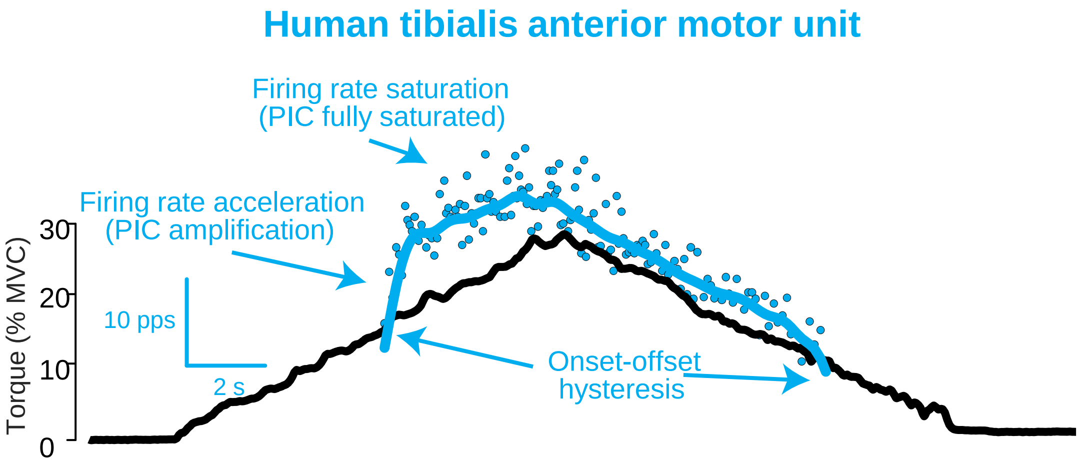
Adapted from Chardon et al. 2023, *eLife*

Adapted from Johnson et al. 2017, *J Neurophysiol*

Plateau potentials – self-sustained firing of motoneurons

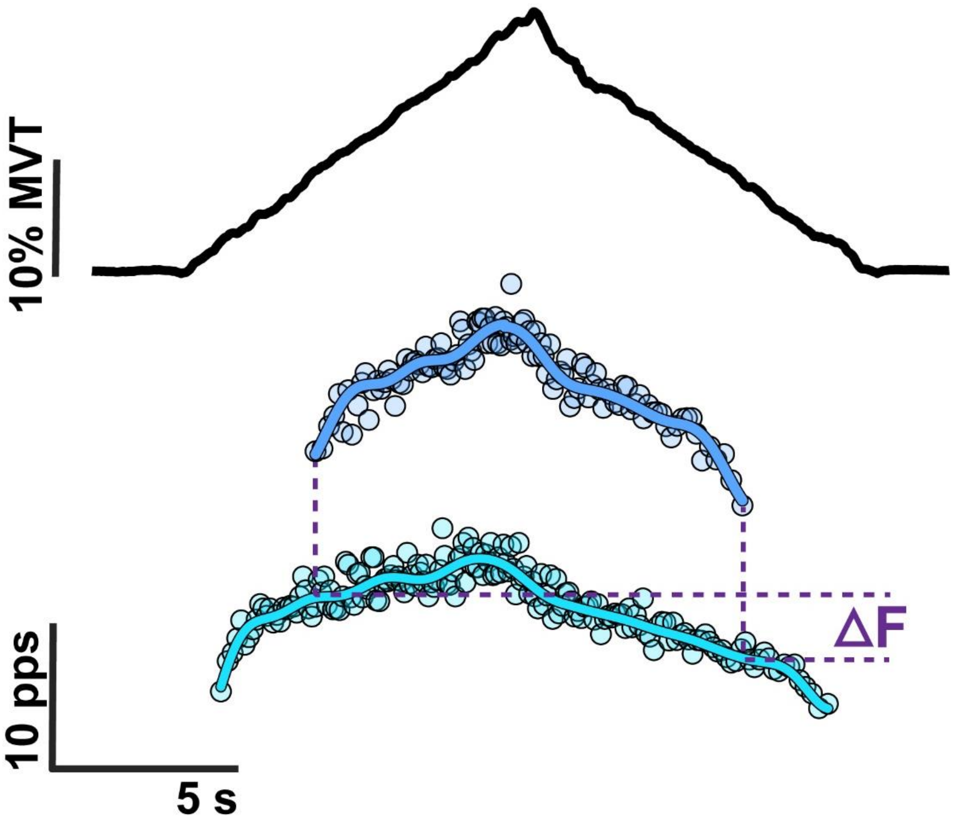




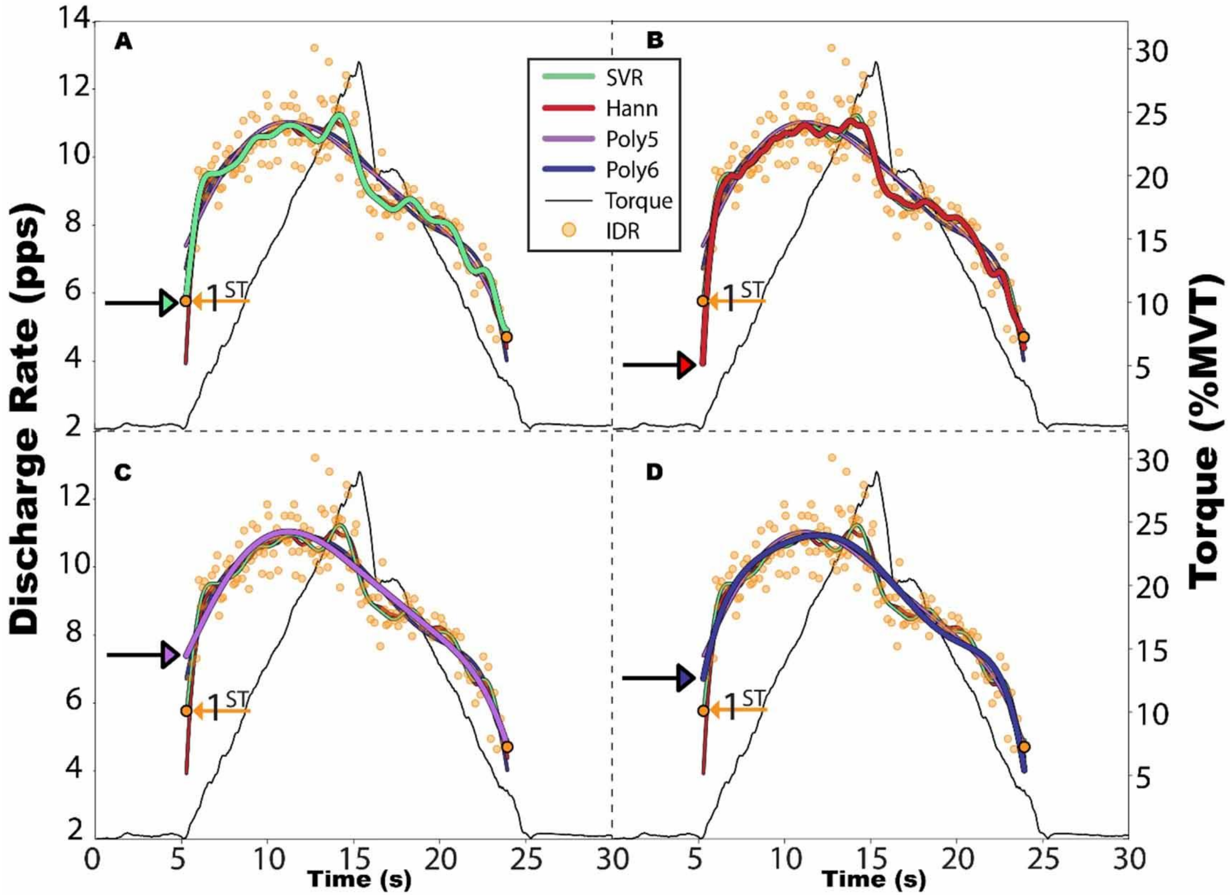


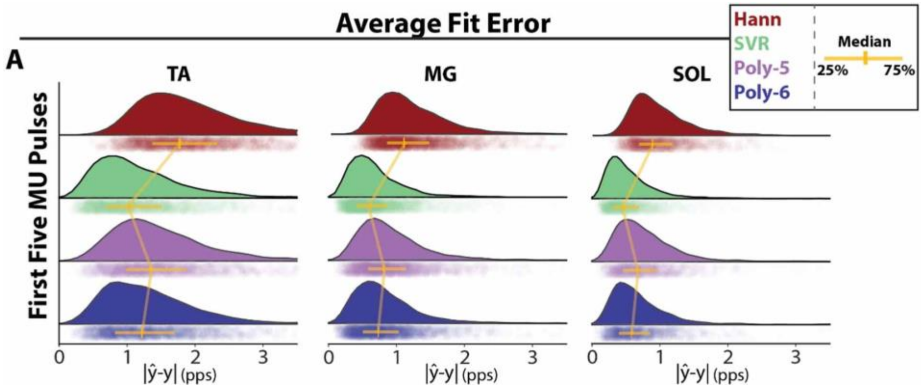
Khurram, Pearcey et al. 2022, *Adv Neurobiol*

Prolongation – hysteresis



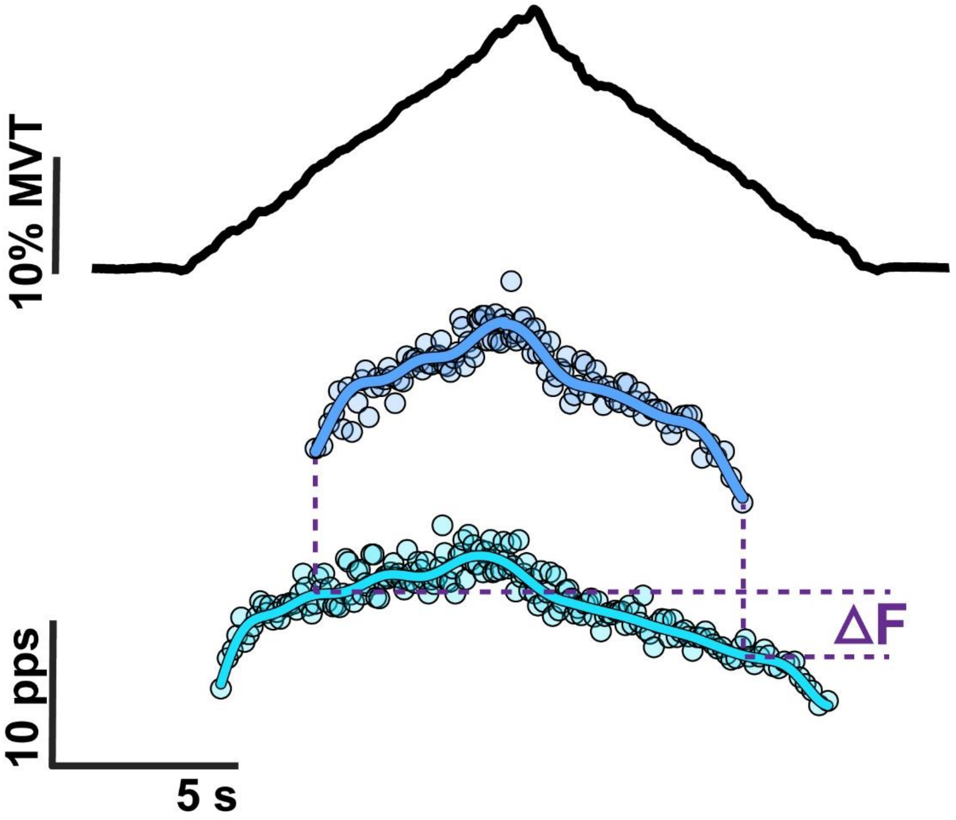
Gorassini et al. 1998, *Neurosci Lett*





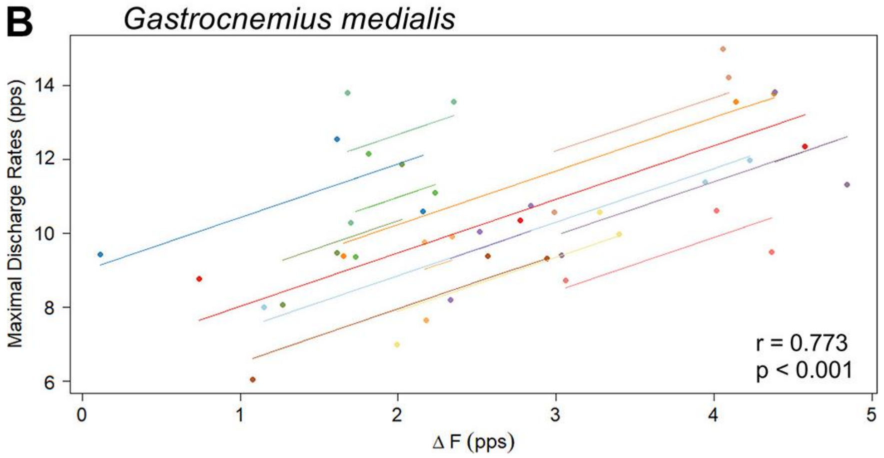
Beauchamp et al. 2022, *J Neural Eng*

Discharge rate hysteresis

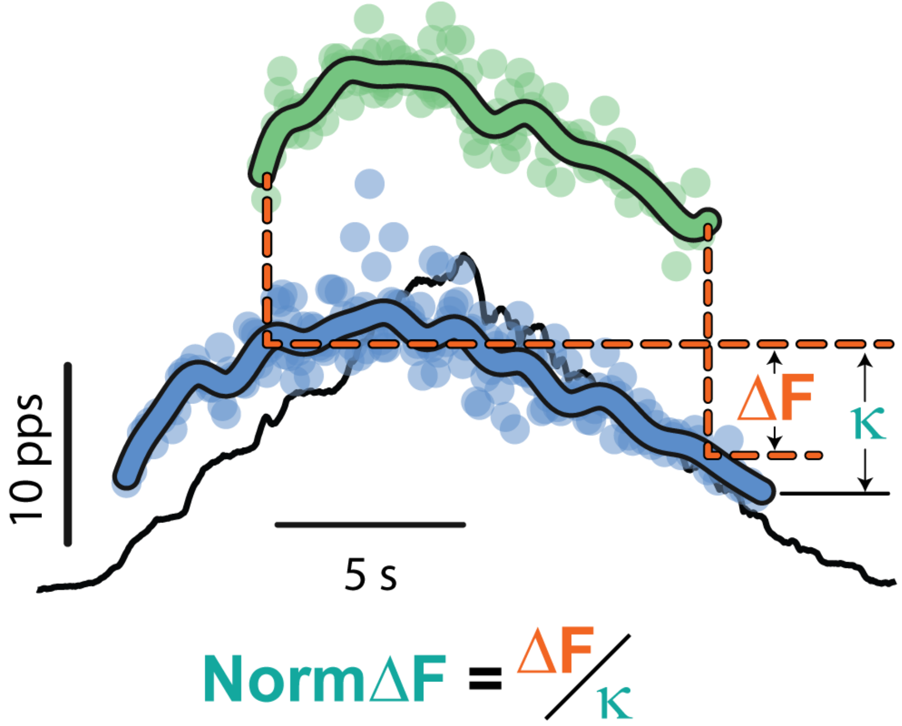


Beauchamp et al. 2023, *J Neural Eng*

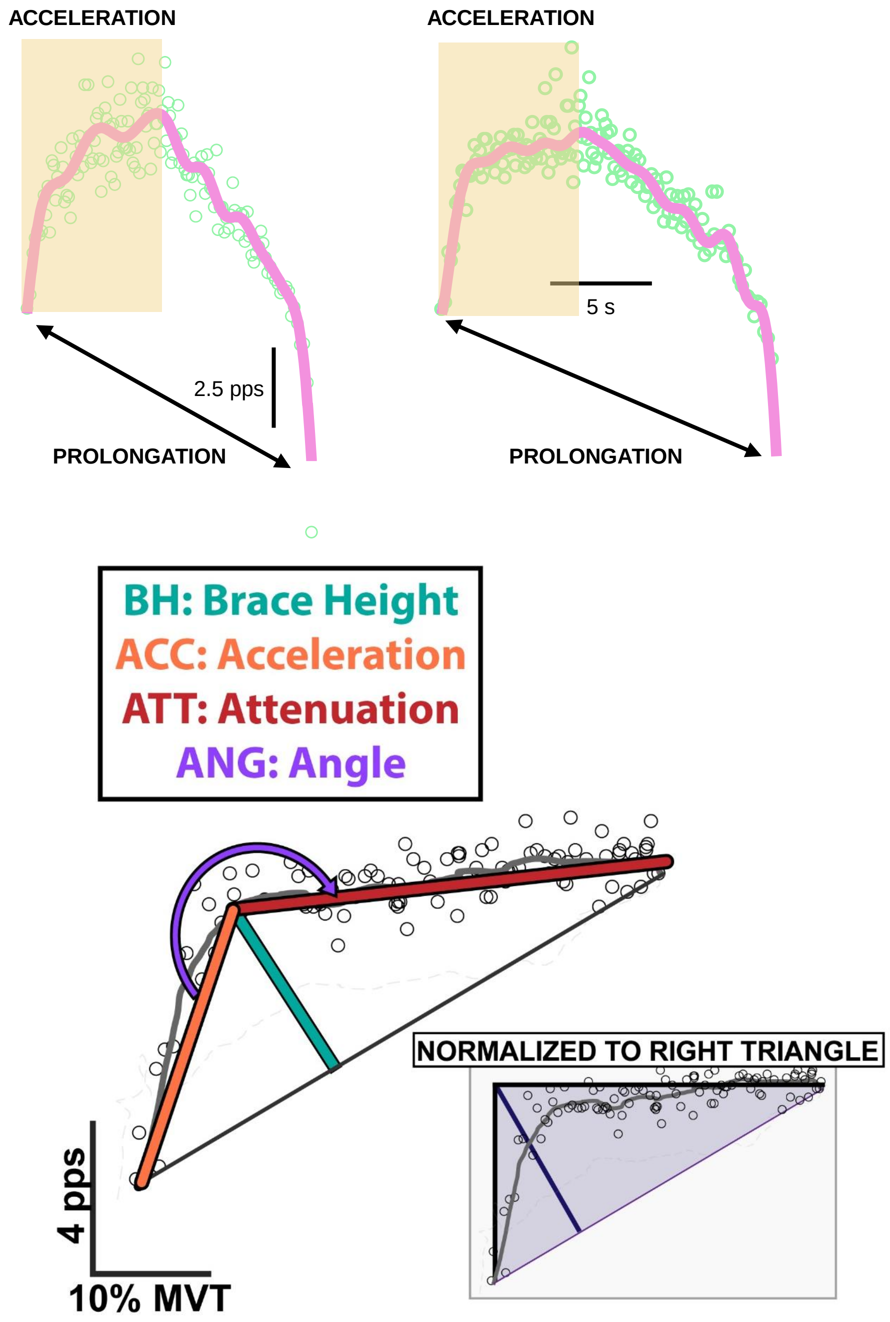
- Rate-rate correlation $R^2 > 0.7$
- Recruitment time difference > 1 s
- Reporter (control) unit discharge rate modulation > 0.5 pps

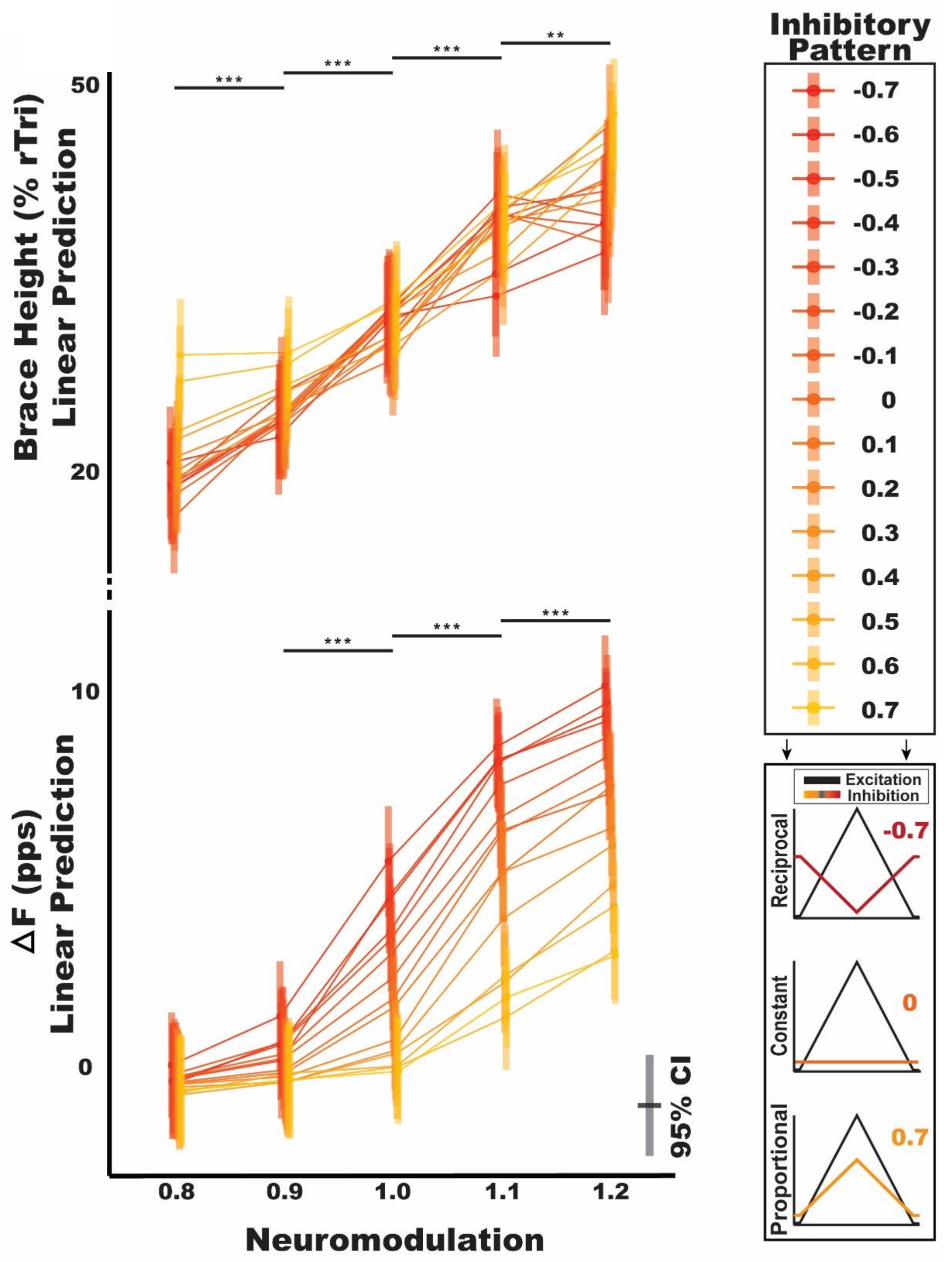


Orssatto et al. 2021, *J Neurophysiol*



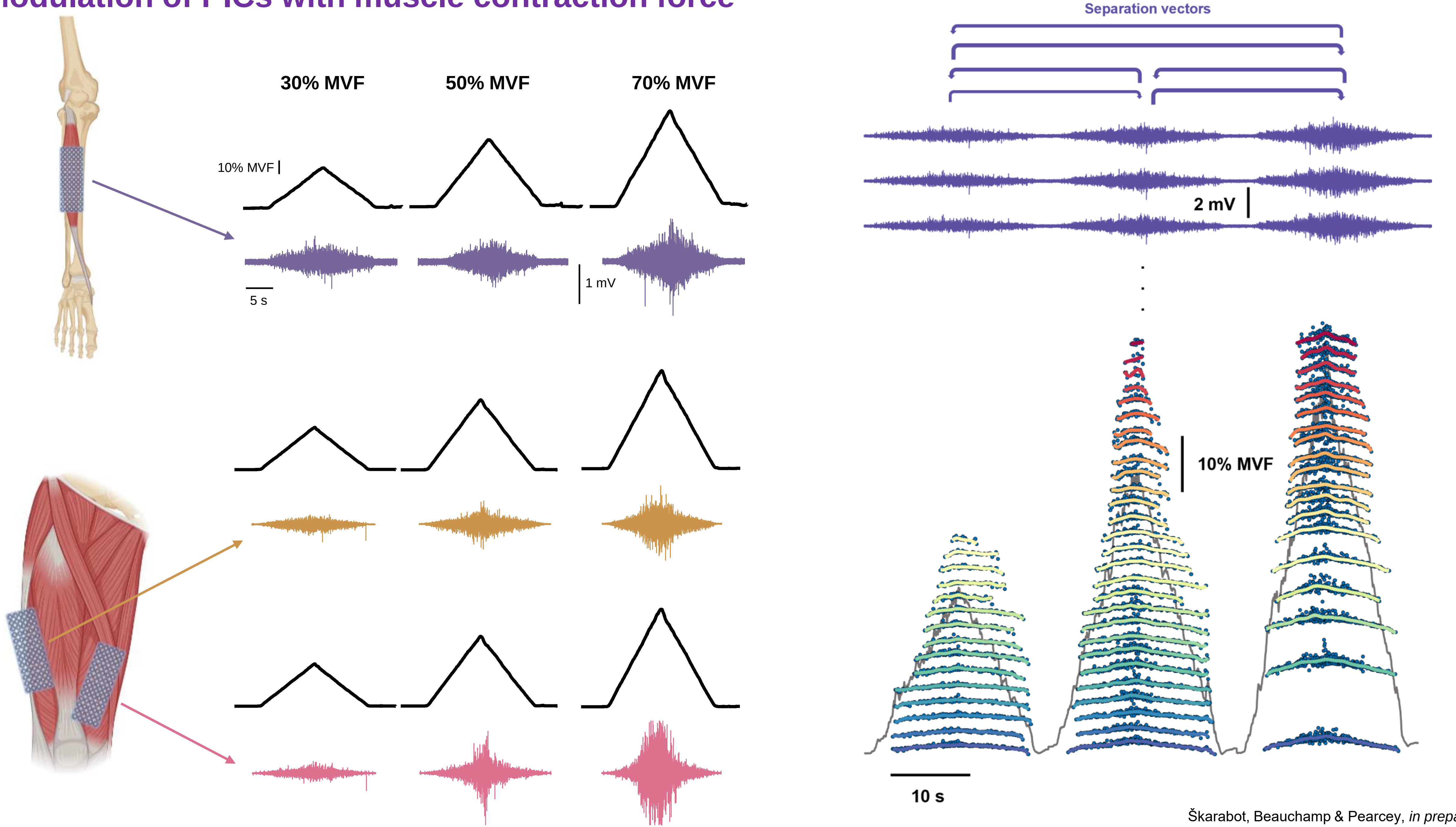
Škarabot et al. 2023, *bioRxiv*





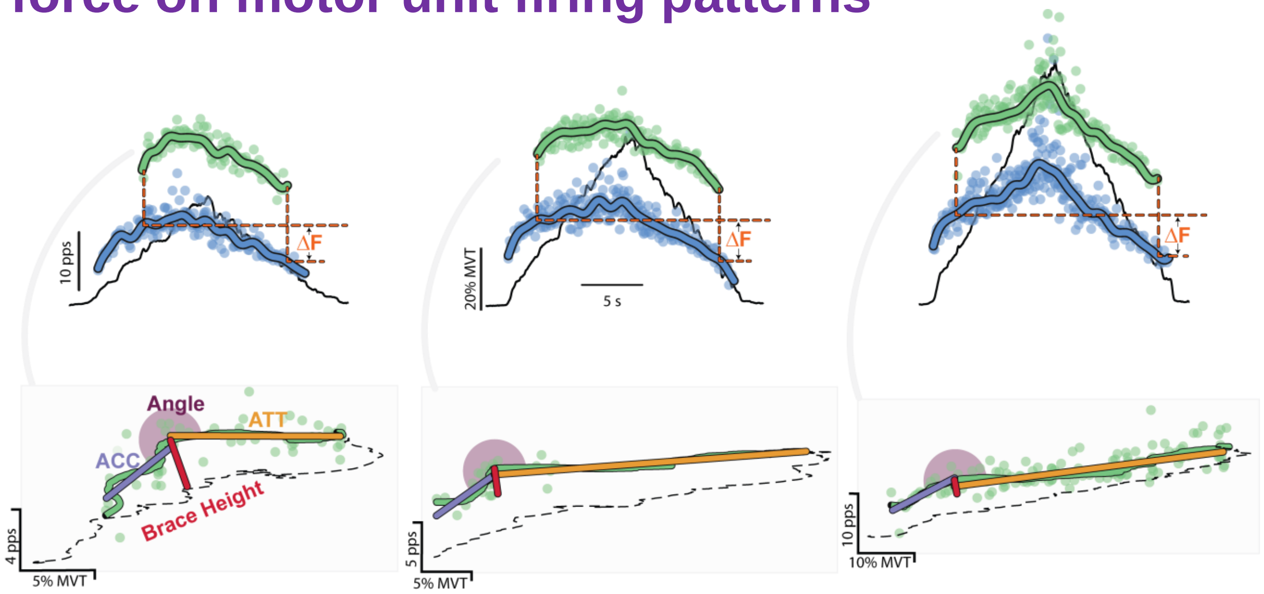
Beauchamp et al. 2023, *J Neural Eng*

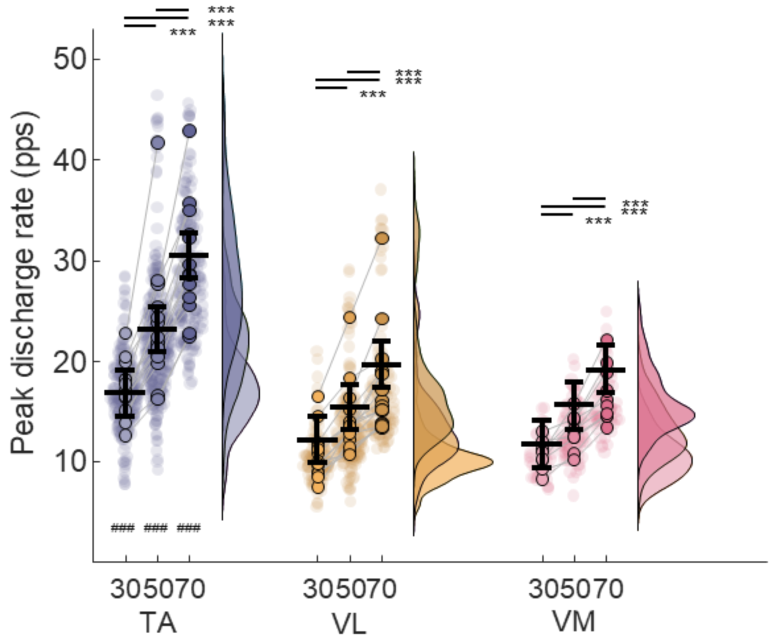
Modulation of PICs with muscle contraction force

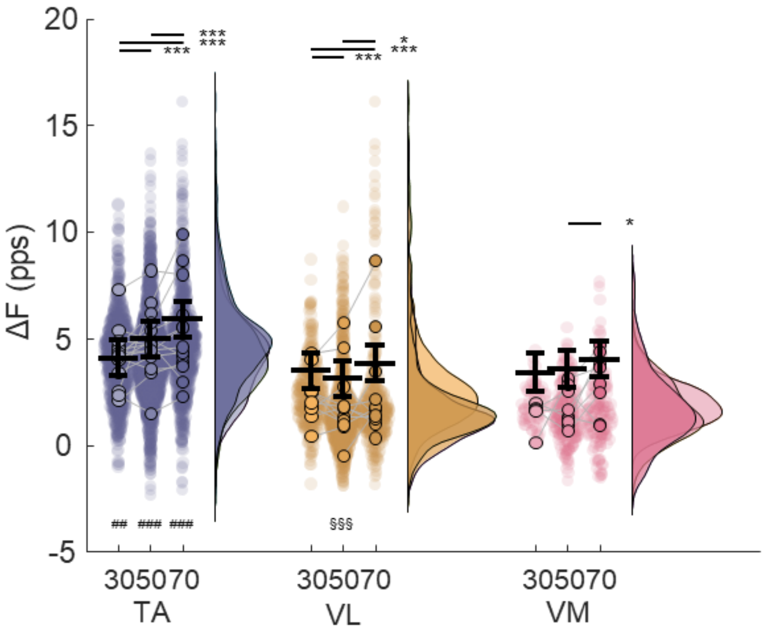


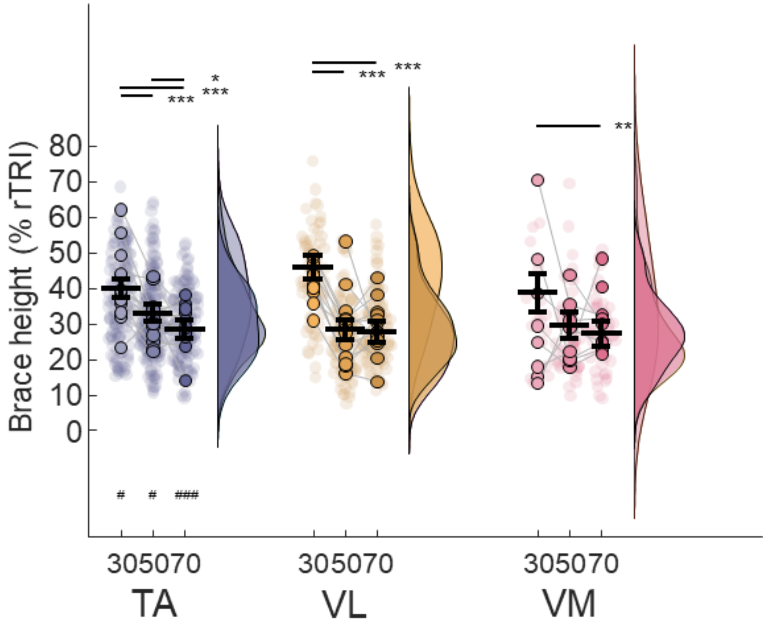
Škarabot, Beauchamp & Pearcey, *in preparation*

The effect of contraction force on motor unit firing patterns



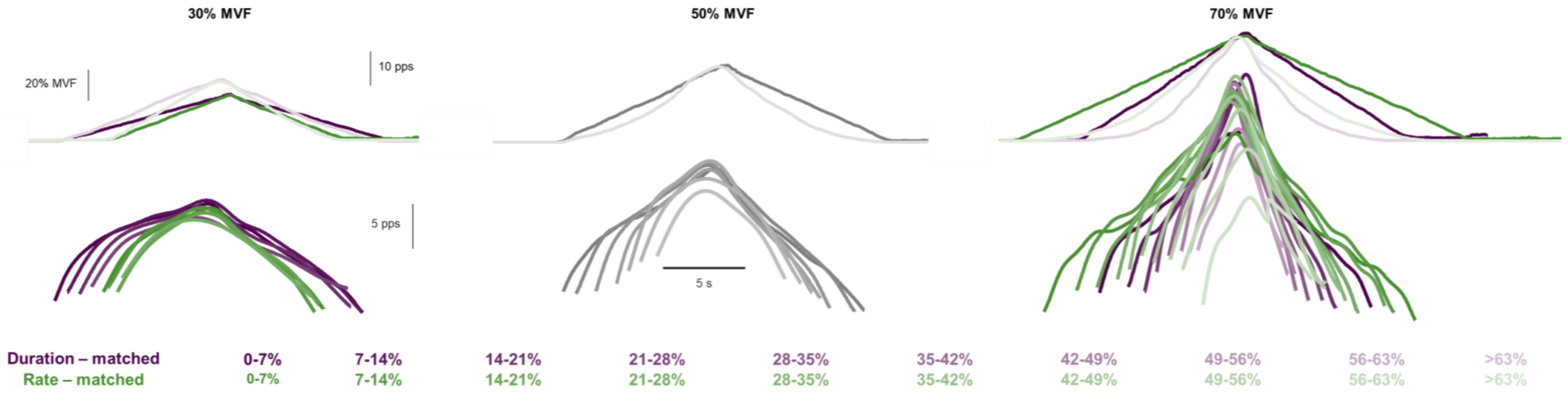


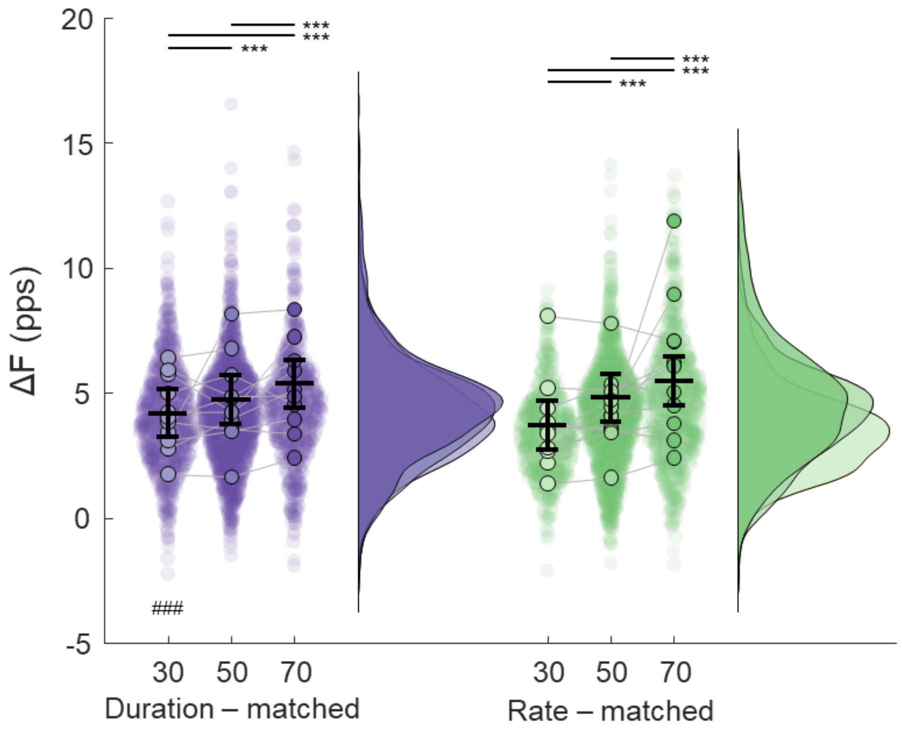


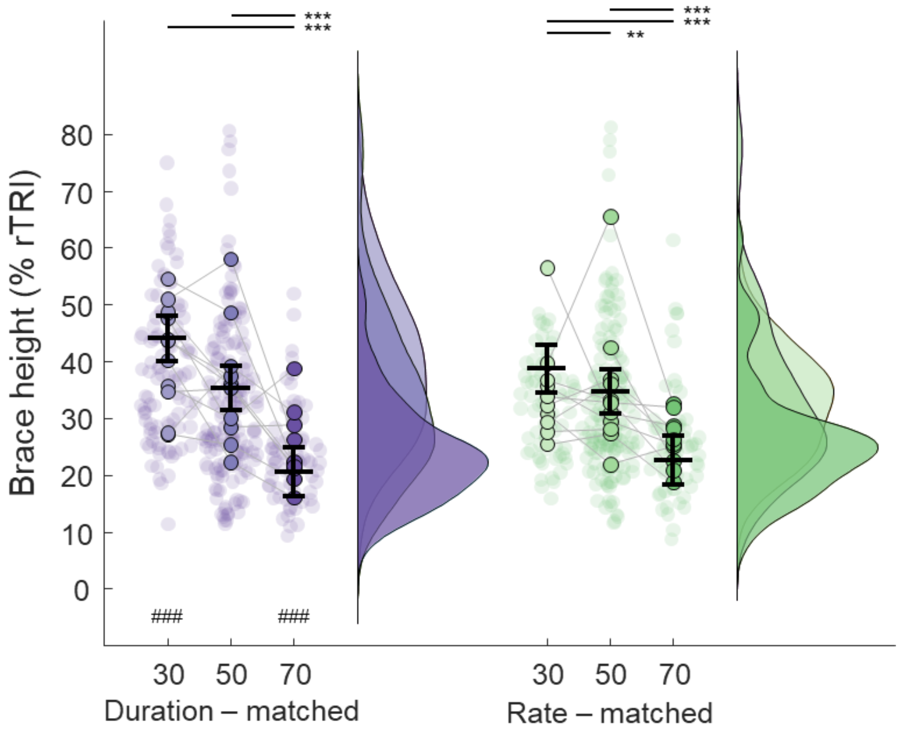


Škarabot, Beauchamp & Pearcey, *in preparation*

The effect of the rate of force increase on motor unit firing patterns

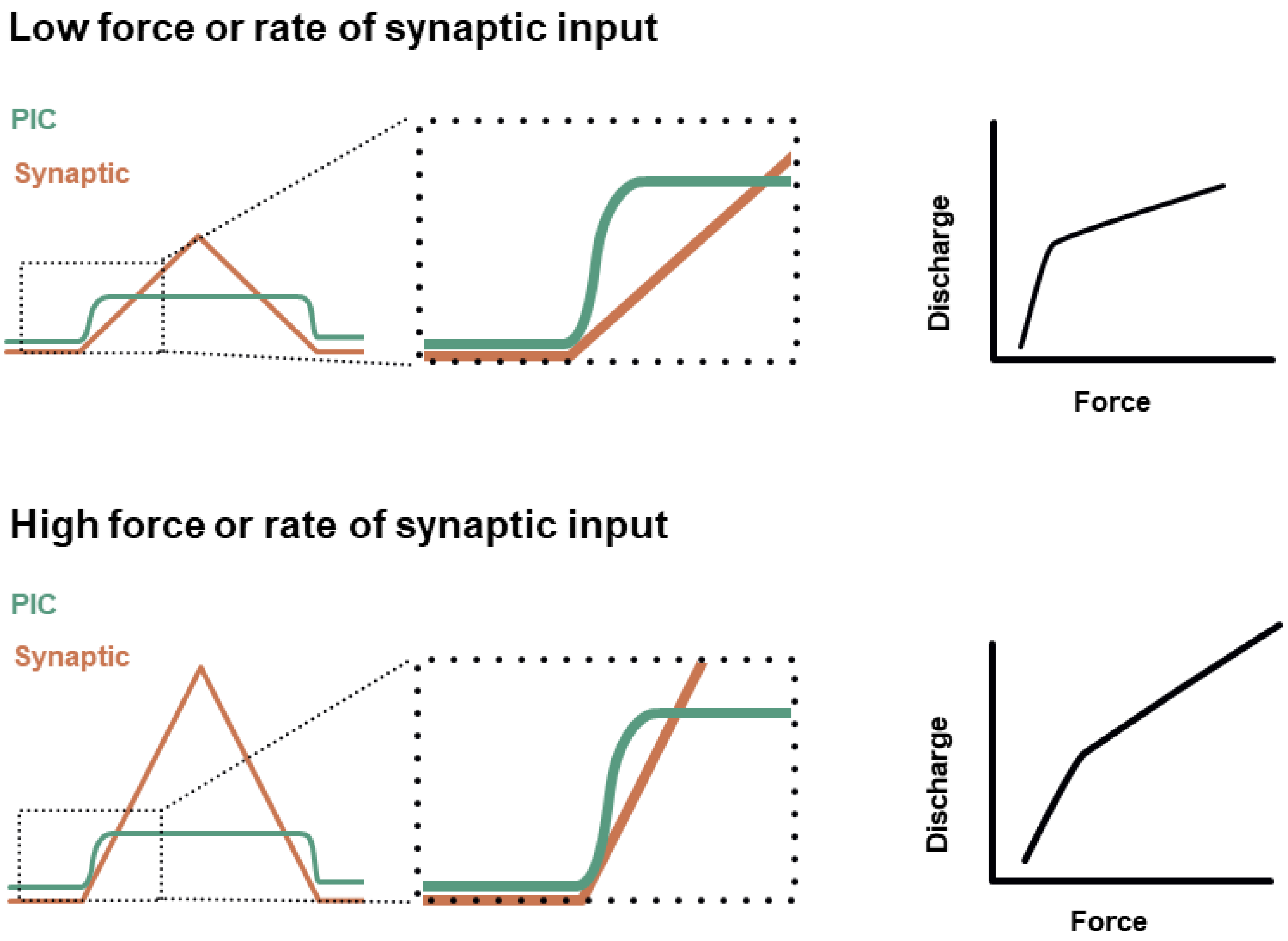






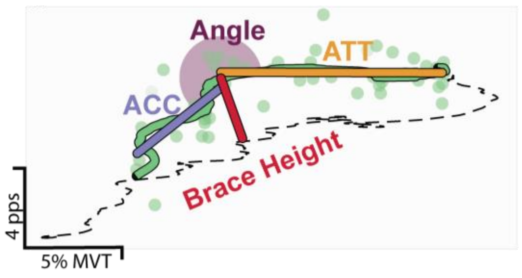
Škarabot, Beauchamp & Pearcey, *in preparation*

Inputs to motoneurons are uniquely shaped to support greater contraction force

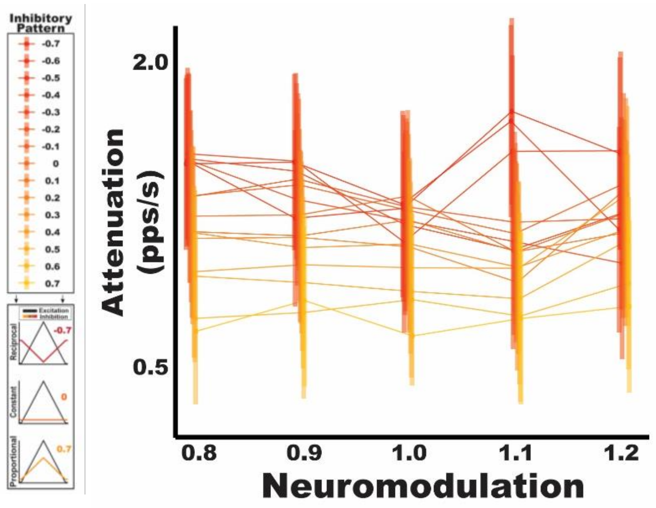


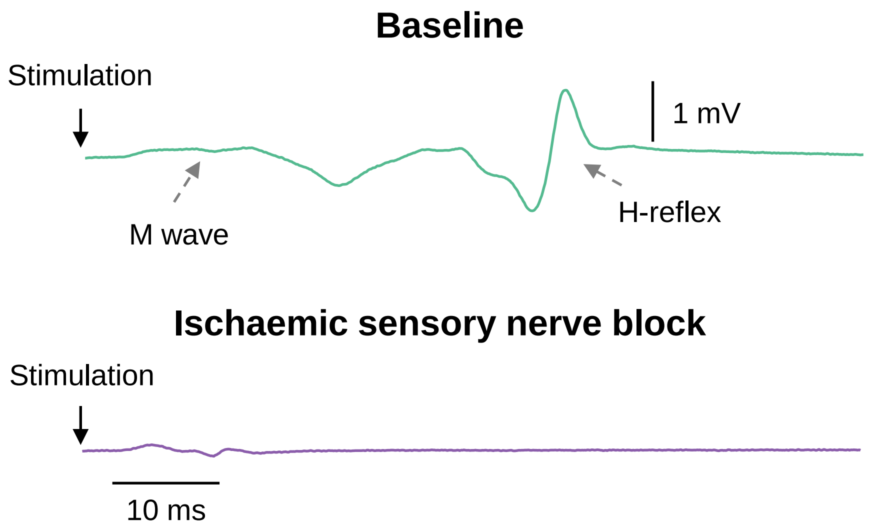
Škarabot, Beauchamp & Pearcey, *in preparation*

Inferring the inhibitory patterns

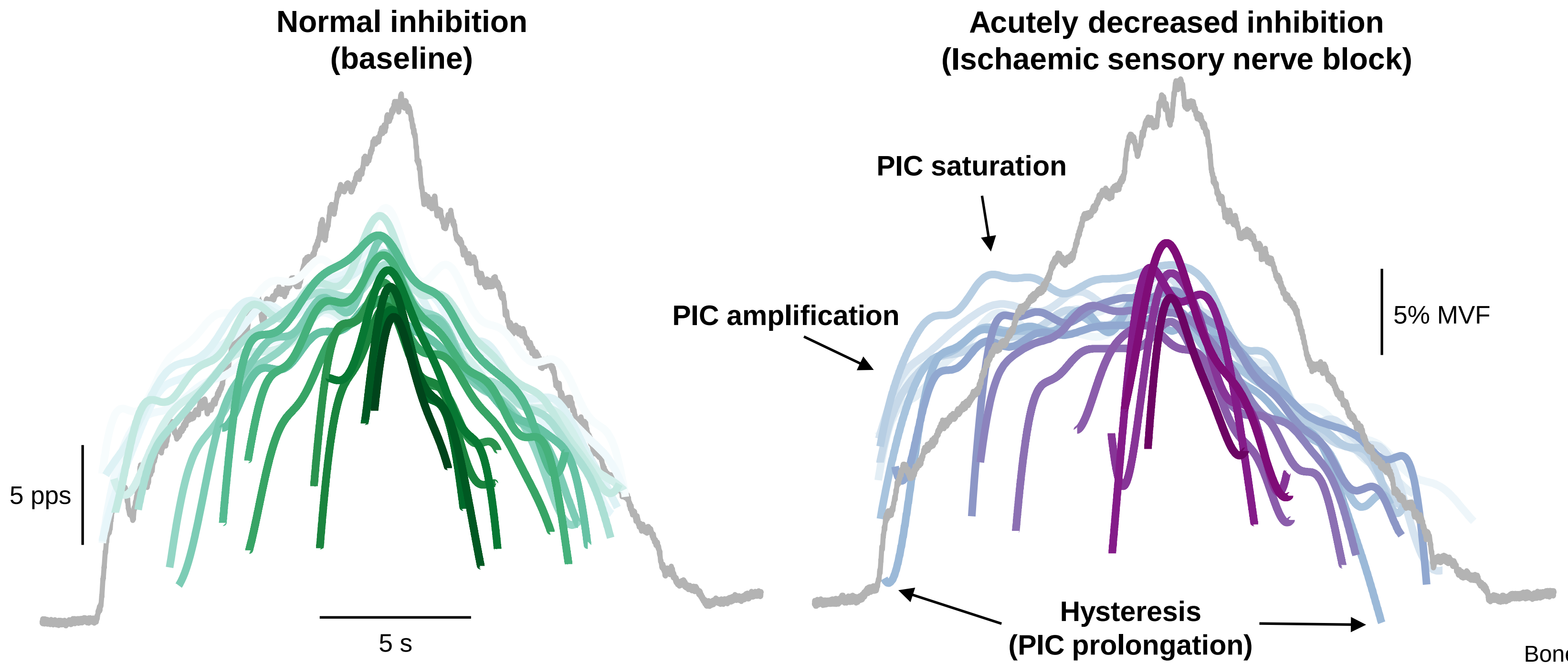


Beauchamp et al. 2023, *J Neural Eng*



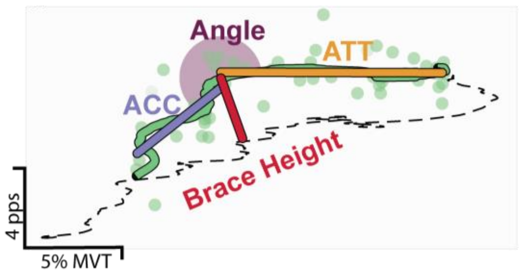


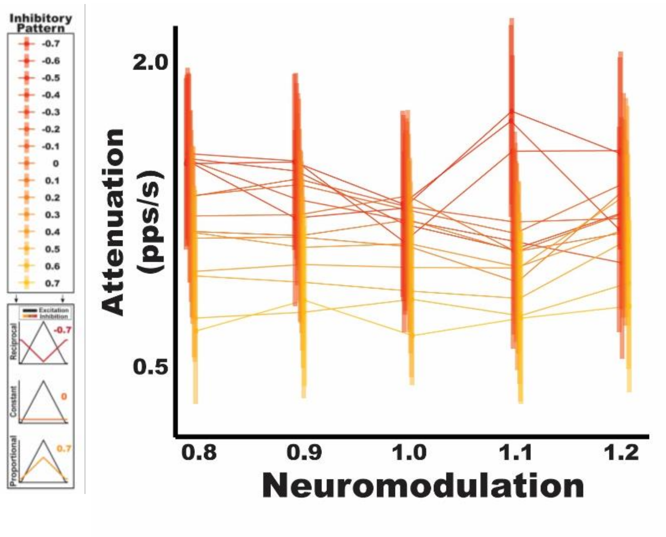
Nikki Bonett



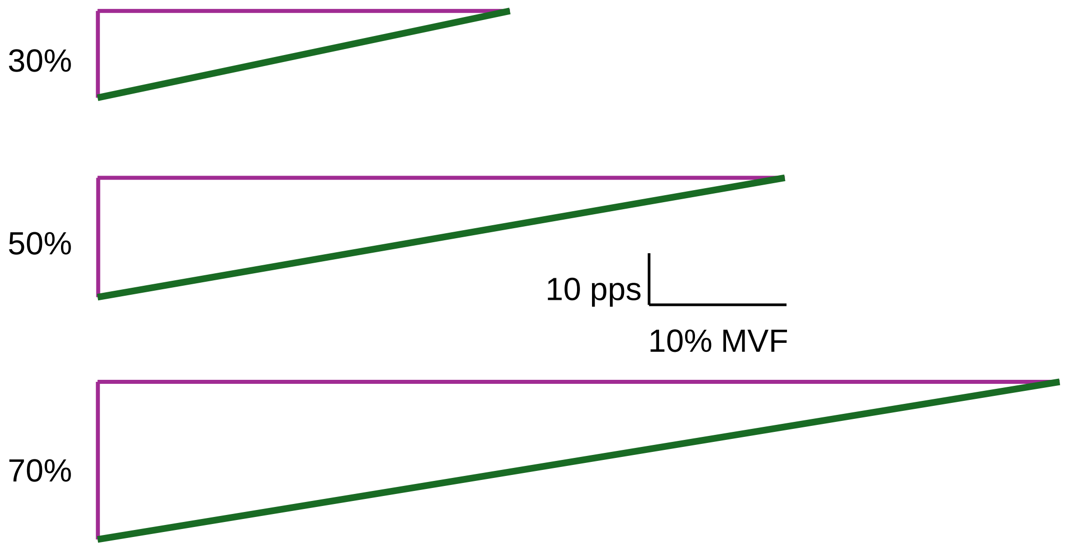
Bonett et al., *in preparation*

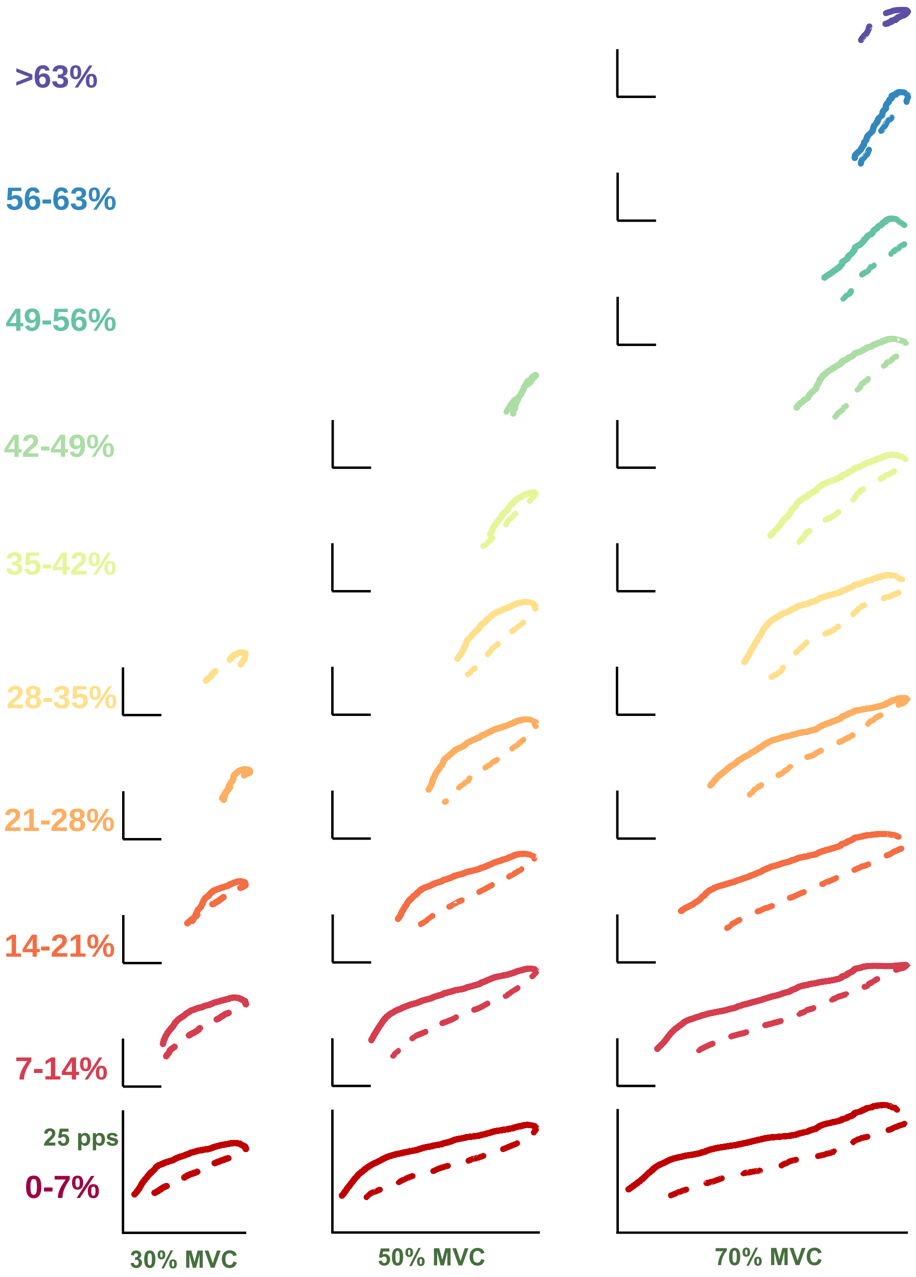
Inferring the inhibitory patterns





Beauchamp et al. 2023, *J Neural Eng*

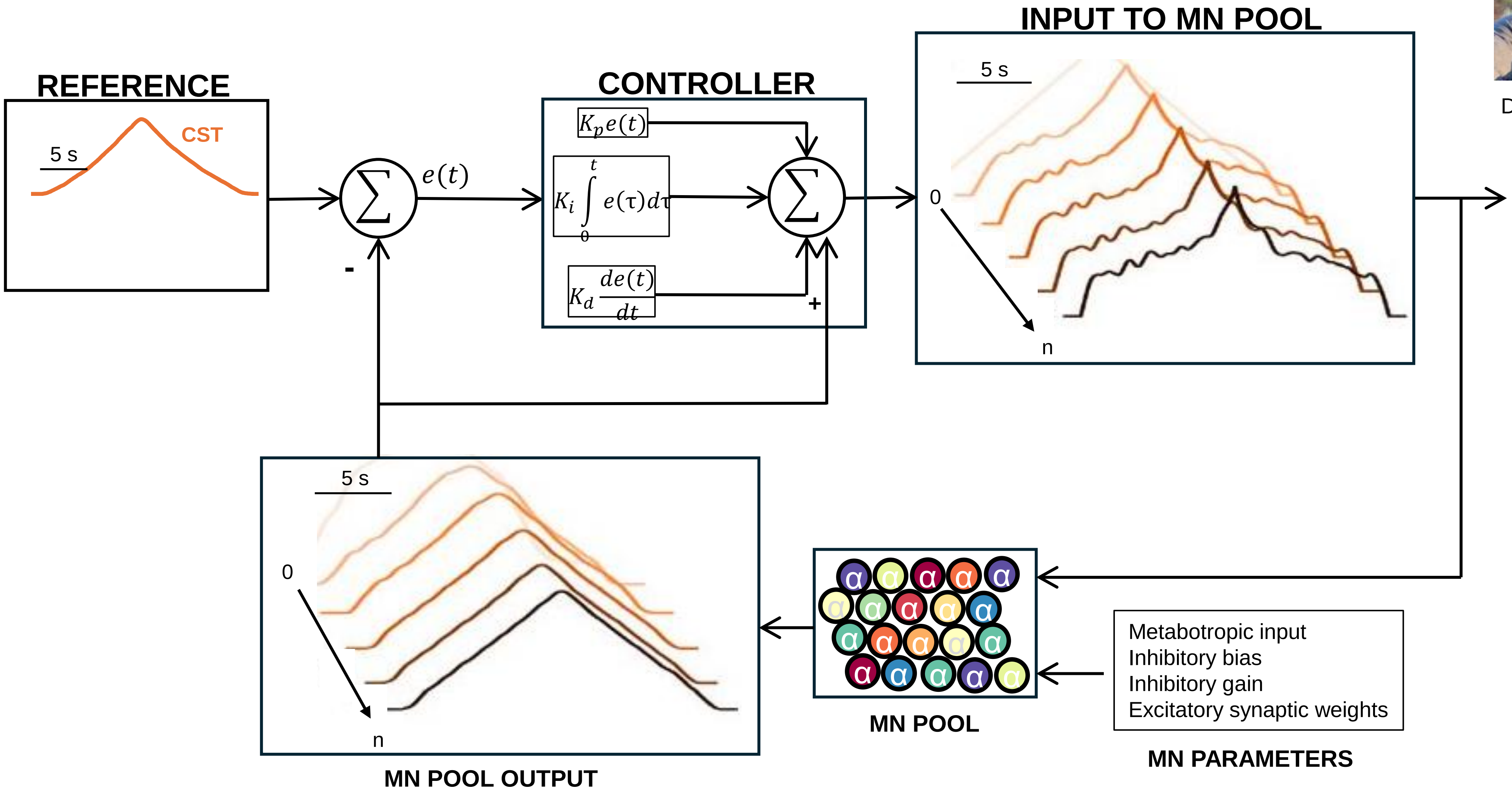




Beauchamp et al. 2013, *J Neural Eng*

Škarabot, Beauchamp & Pearcey, *in preparation*

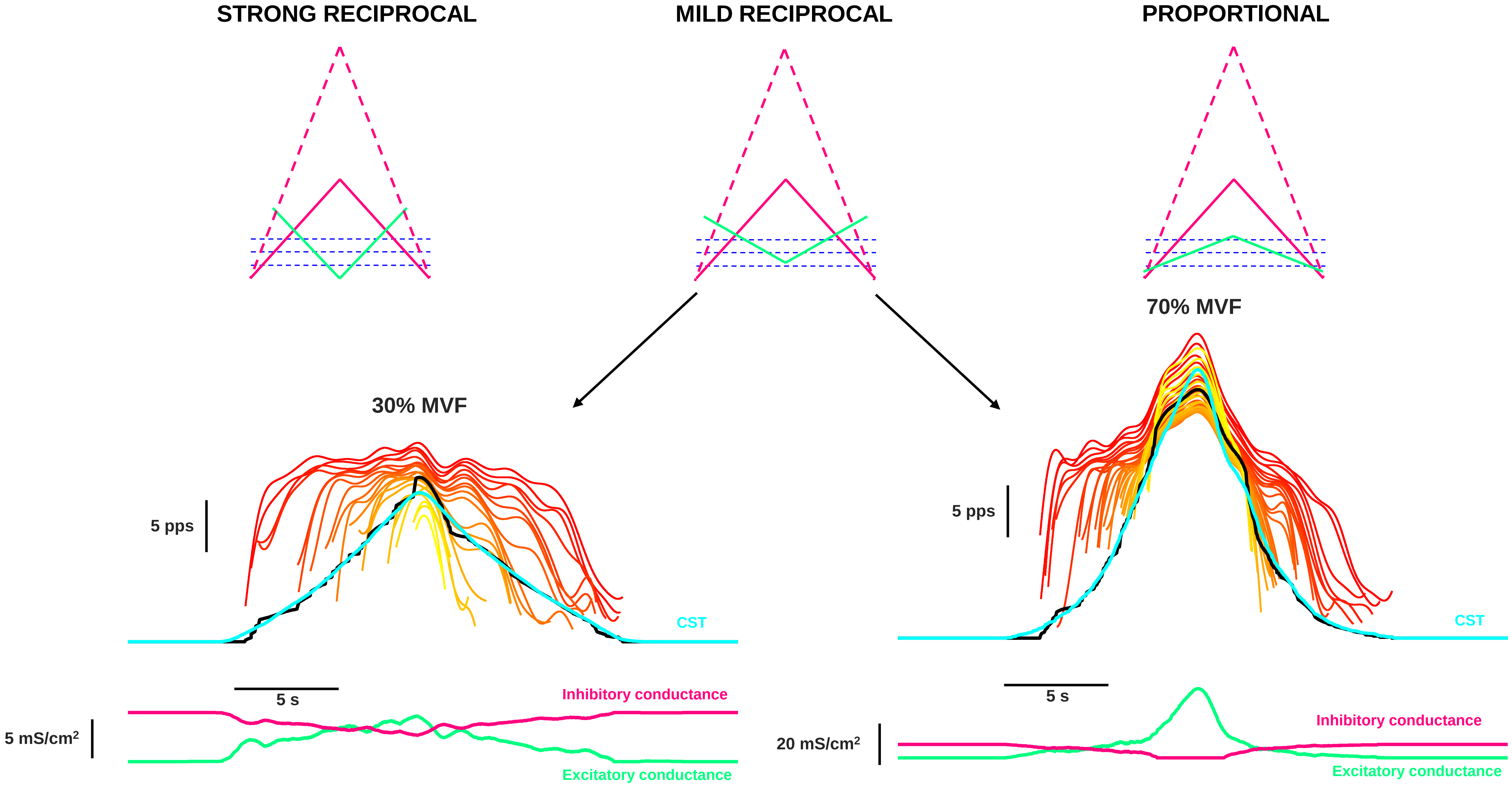
A realistic motoneuron model



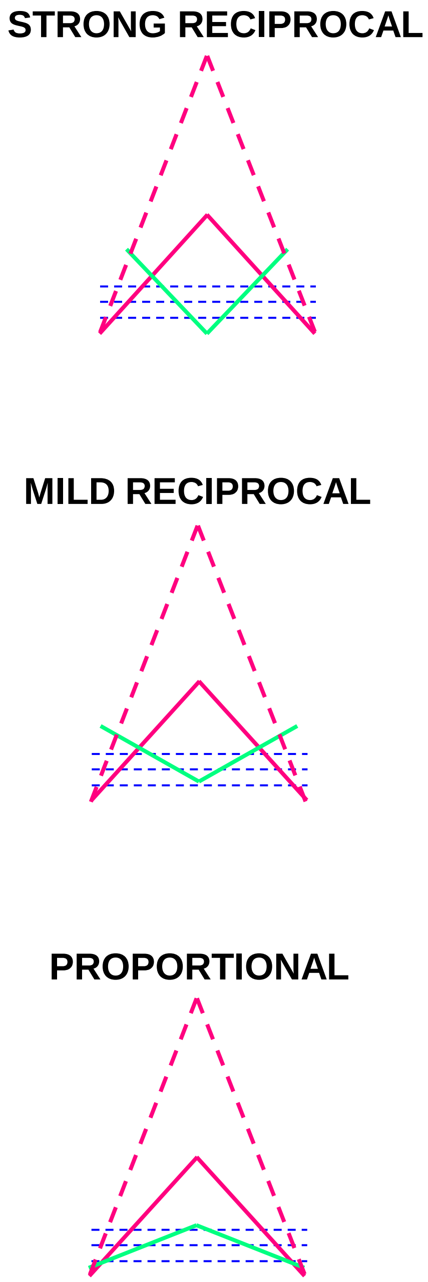
Dr Drew Beauchamp

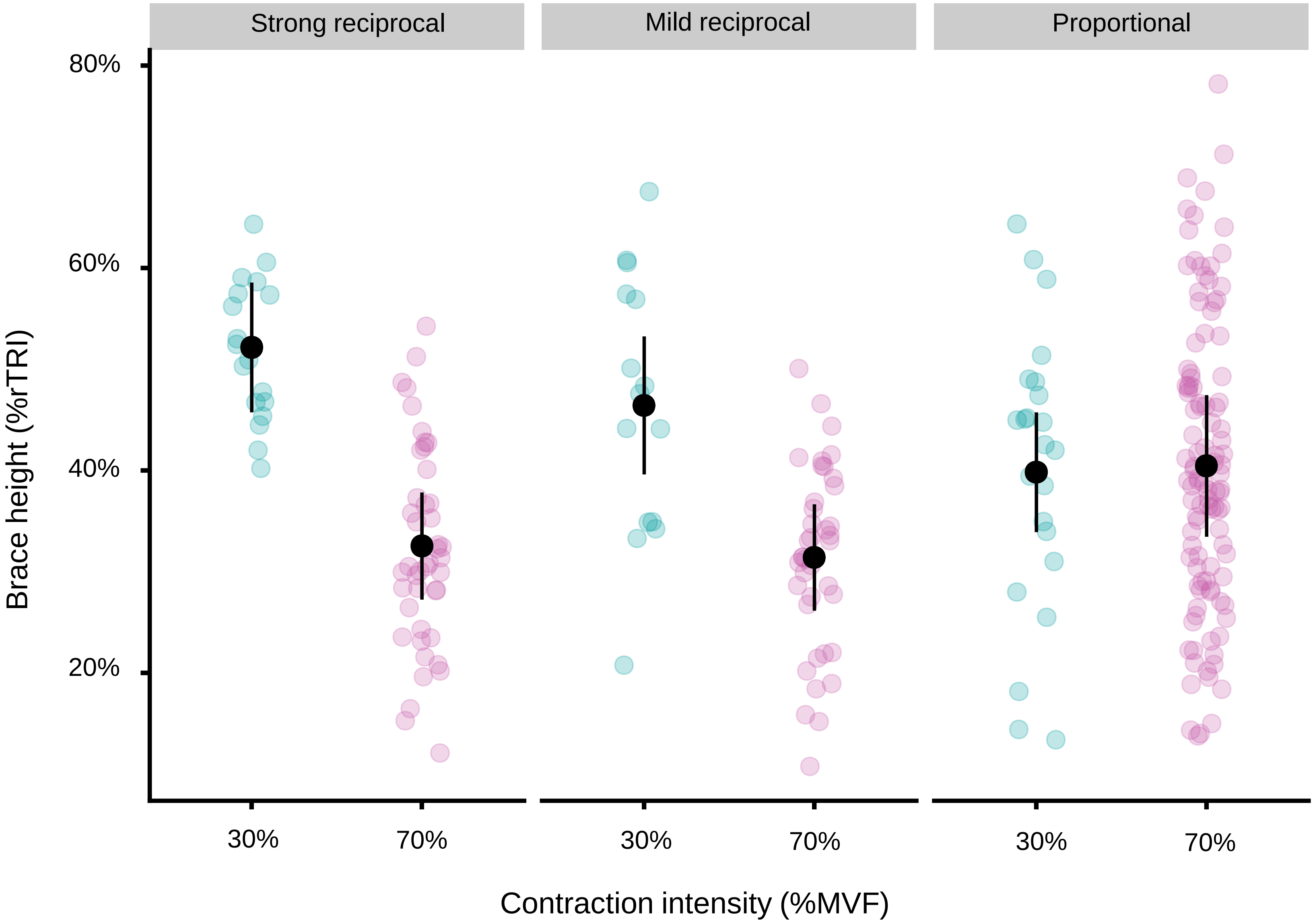
Adapted from Chardon et al. 2023, *eLife*

Simulated inputs to motoneuron pool



Škarabot, Beauchamp & Pearcey, *in preparation*

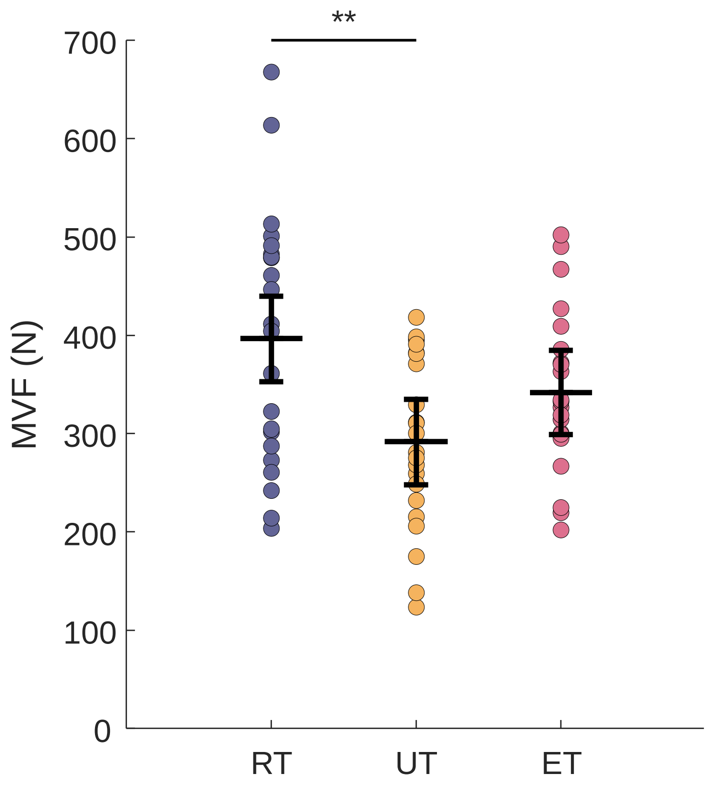


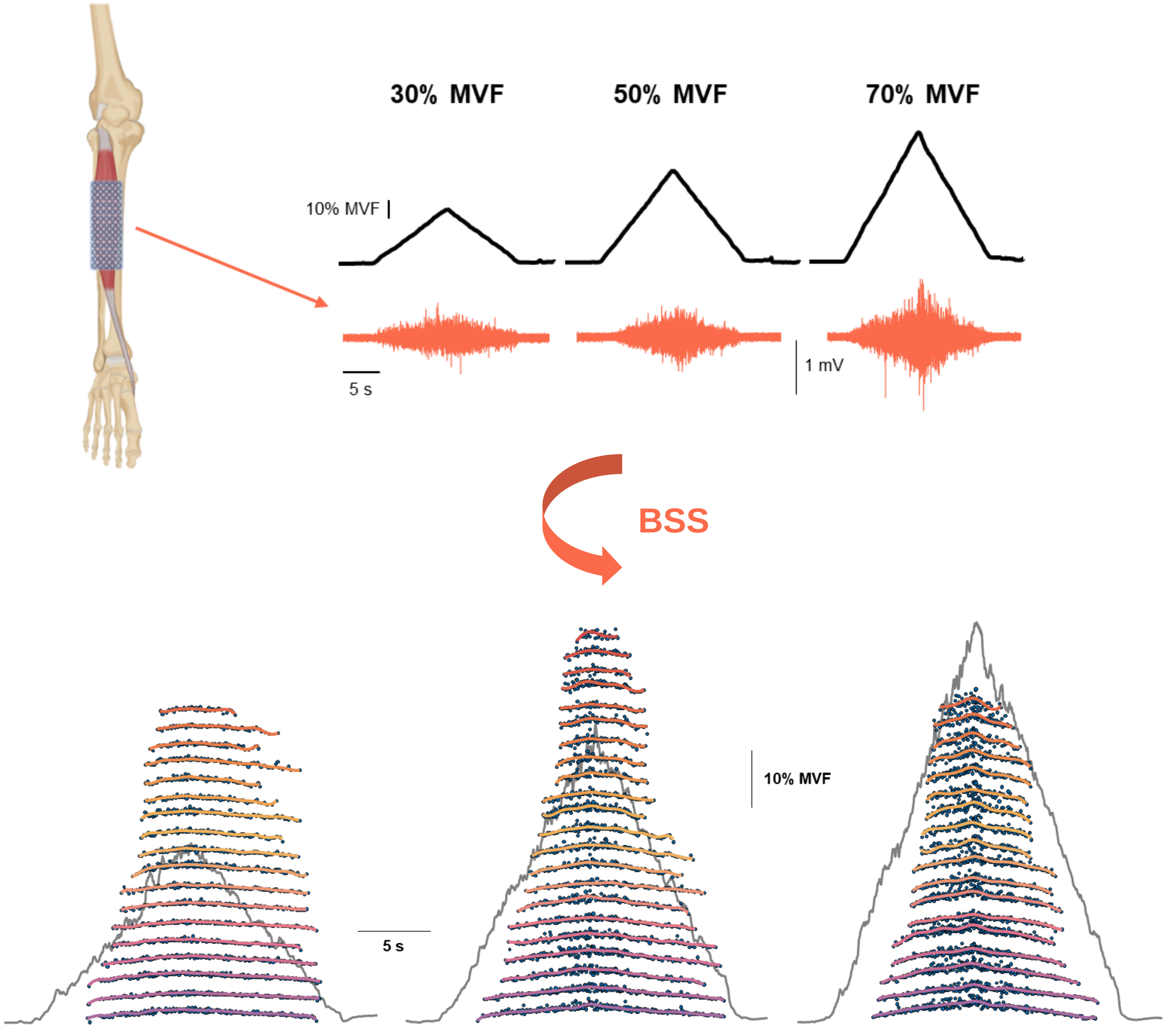


Škarabot, Beauchamp & Pearcey, *in preparation*

Inputs to motoneurons in chronically trained individuals

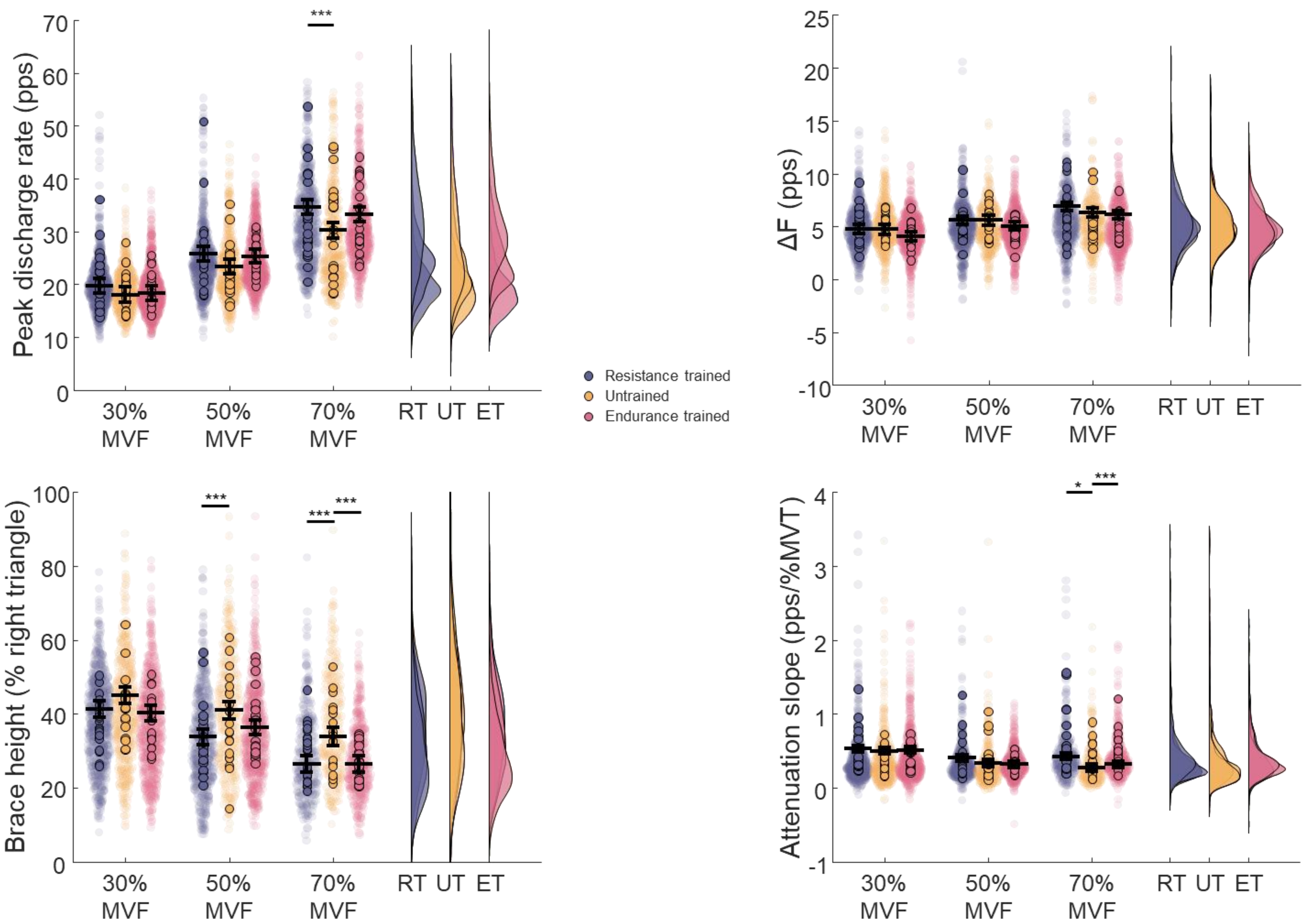
	RT (n=23)	UT (n=23)	ET (n=23)
Training Age (yrs)	9 ± 3	-	10 ± 4
IPAQ (MET-min/week)	**6401± 2729***	4038 ± 2380	**6590 ± 2128****
Mass (kg)	**84 ± 17****	70 ± 12	68 ± 8
Height (m)	1.75 ± 0.08	1.73 ± 0.08	1.78 ± 0.08
Age (yrs)	23 ± 4	23 ± 3	24 ± 6





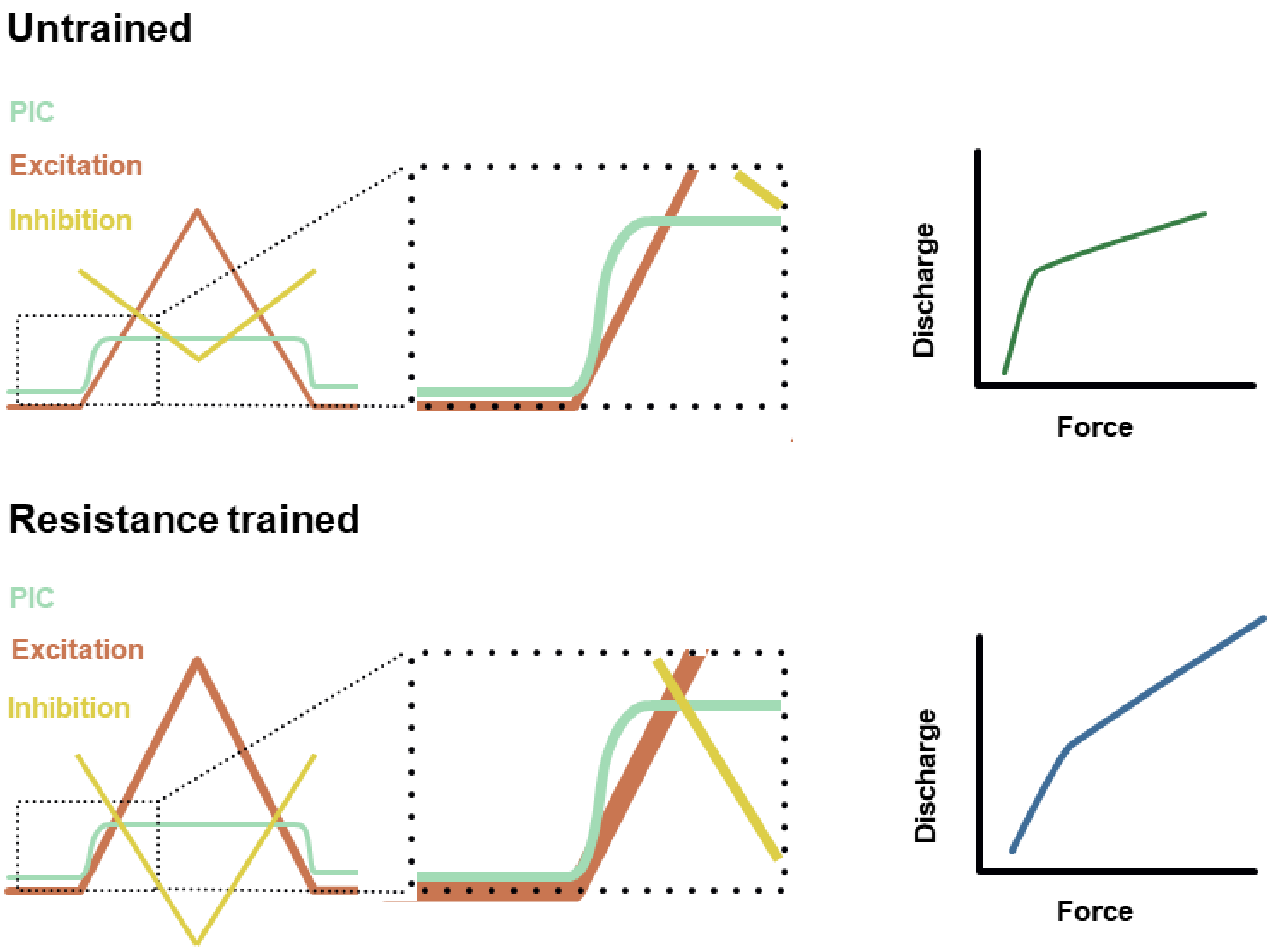
Škarabot, Thomason et al., *in preparation*

Inputs to motoneurons in chronically trained individuals



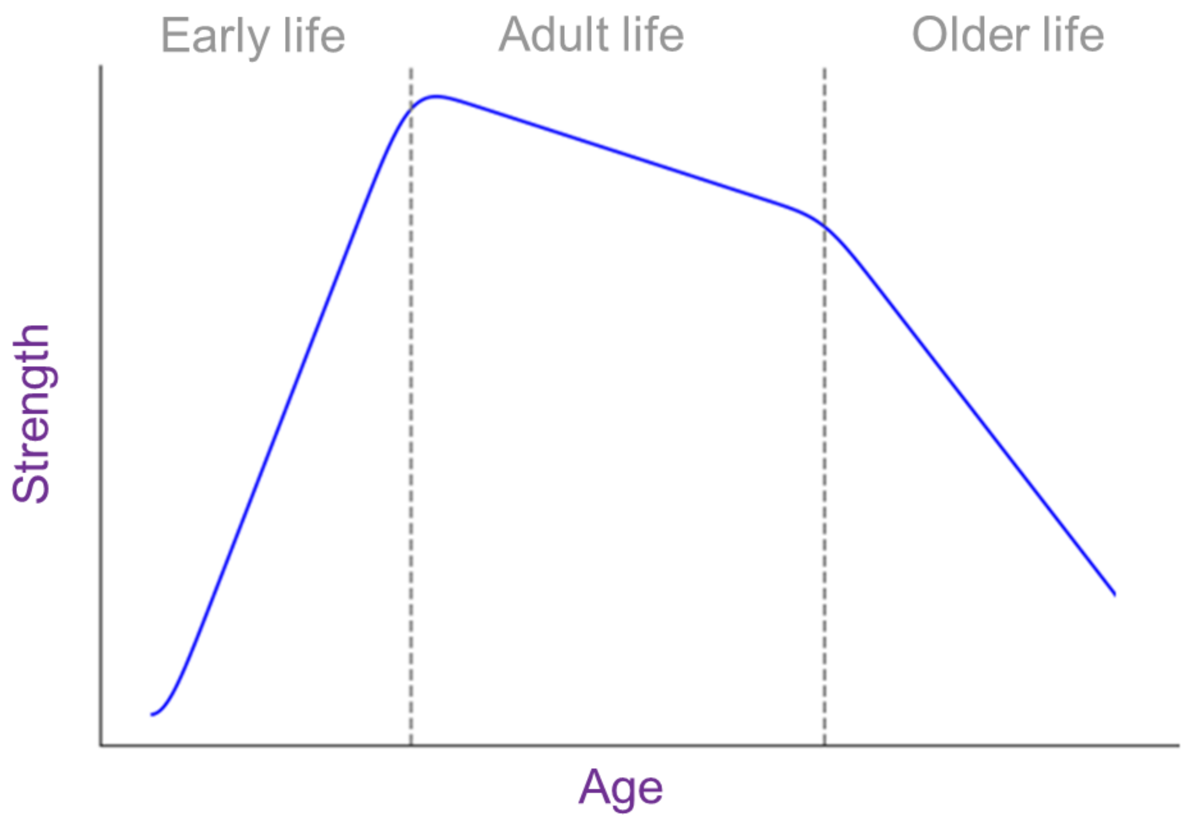
Škarabot, Thomason et al., *in preparation*

Inputs to motoneurons in chronically trained individuals

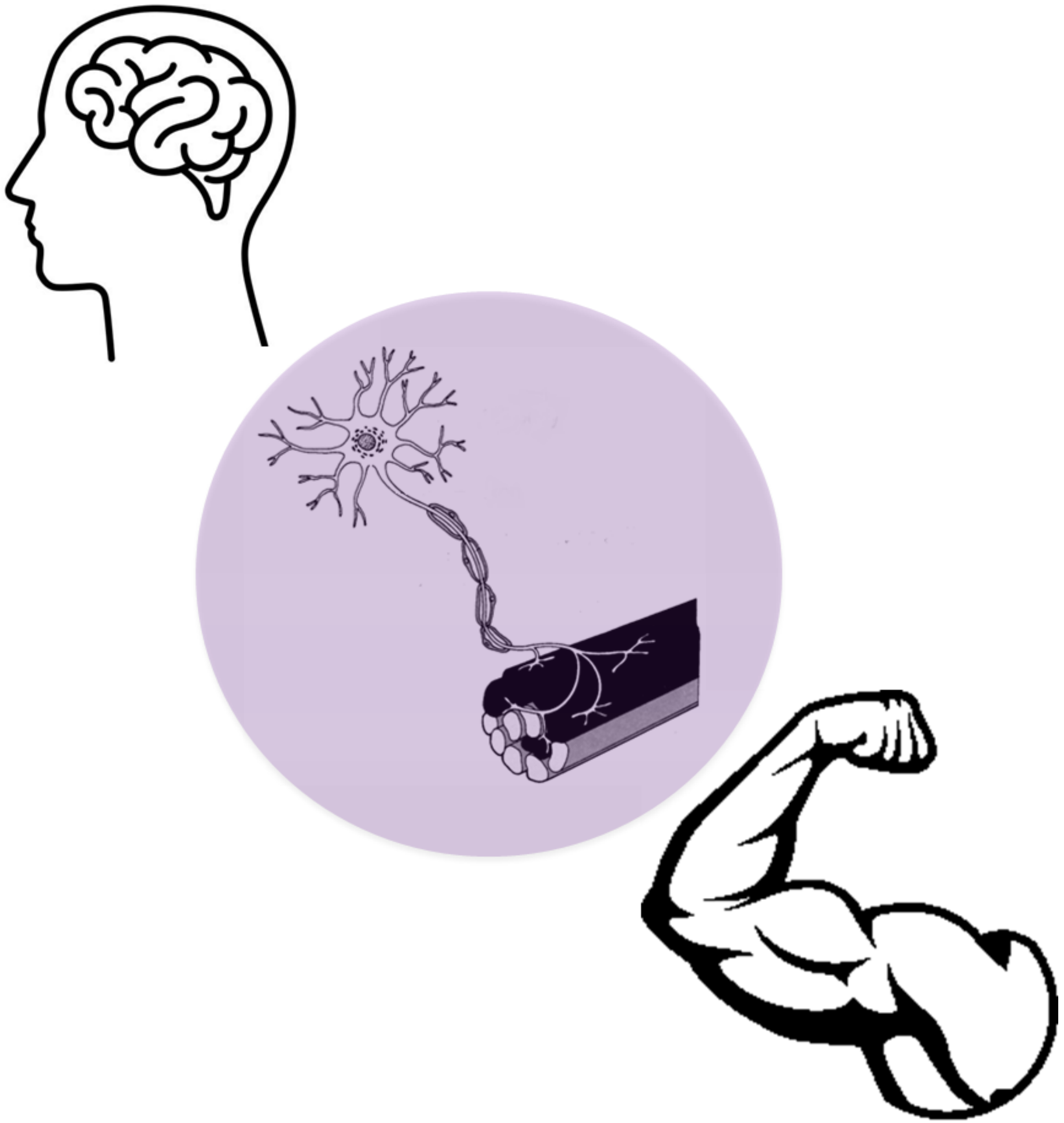


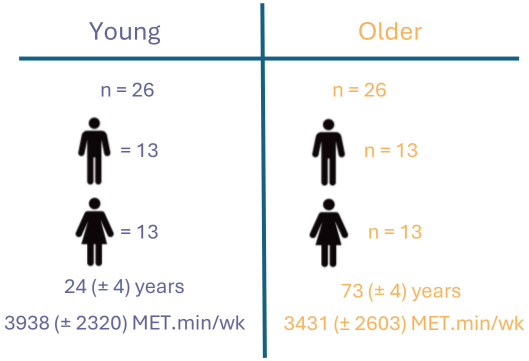
Škarabot, Thomason et al., *in preparation*

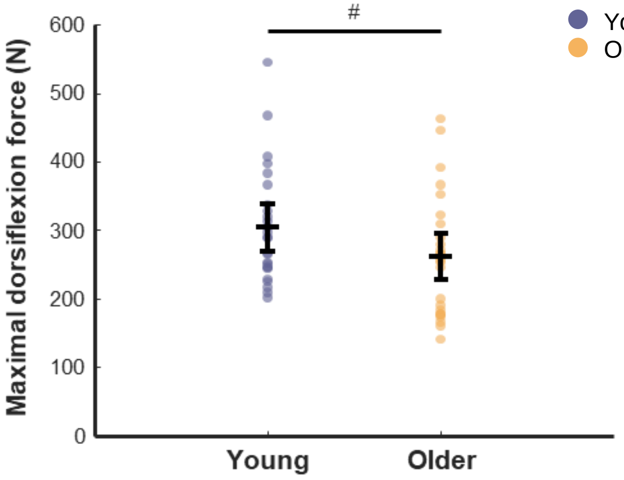
Motoneuron properties in ageing individuals

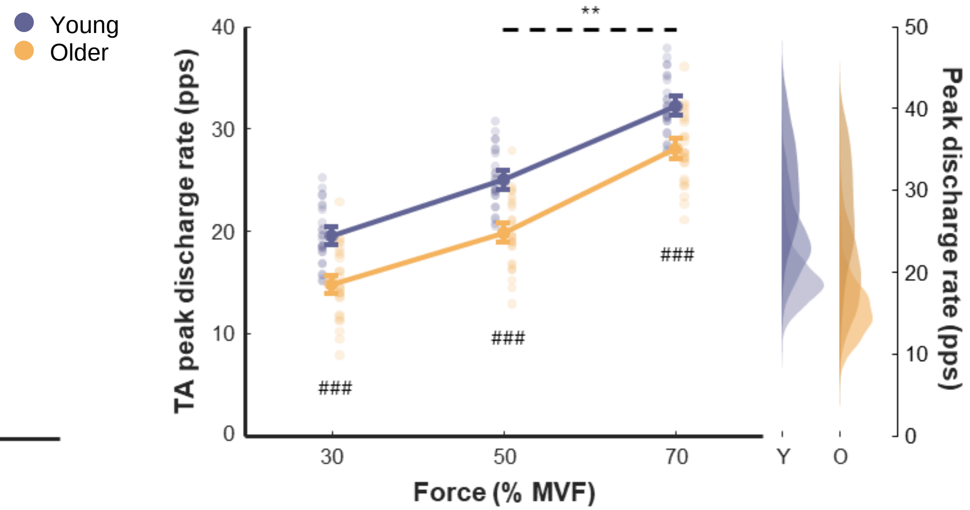


(Adapted from Guyton & Hall, 1996)



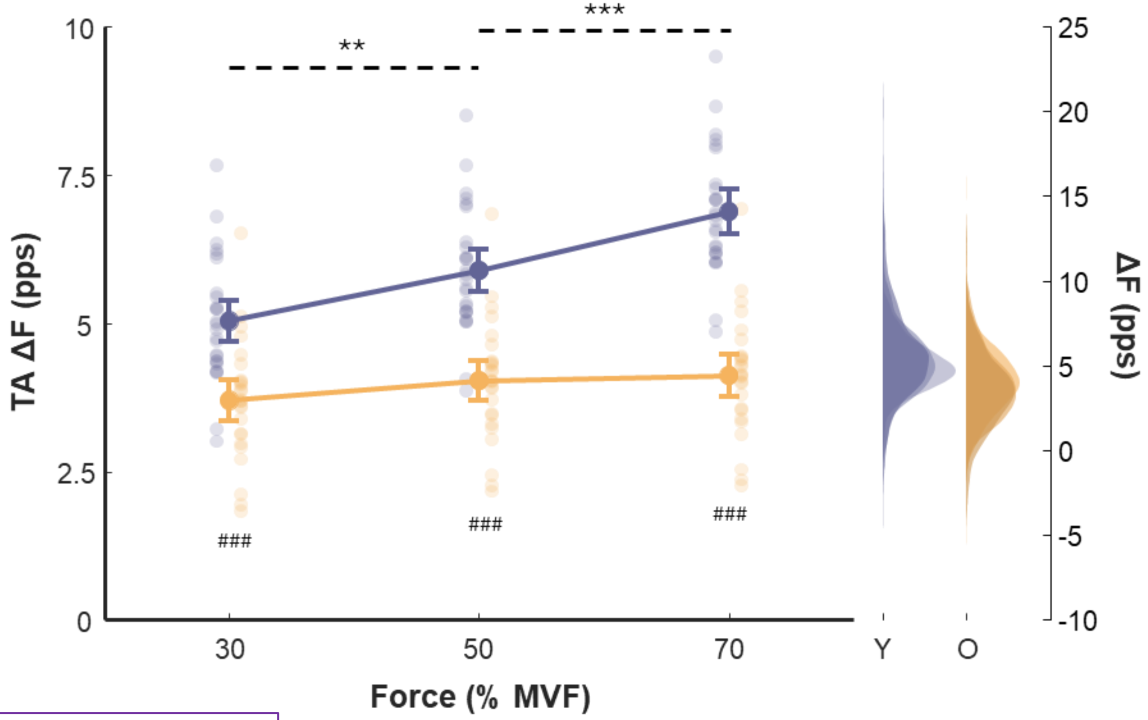




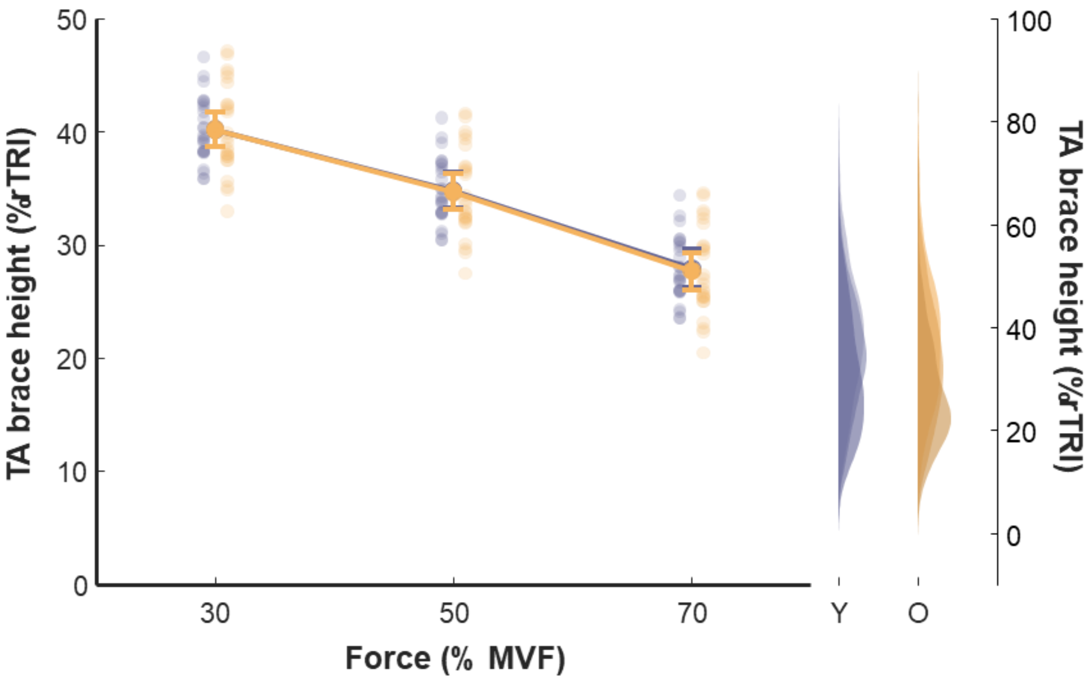


Chris Connelly

Neuromodulation
Inhibition



Neuromodulation



Difference between groups
* Interaction contrast

Connelly et al., *in preparation*

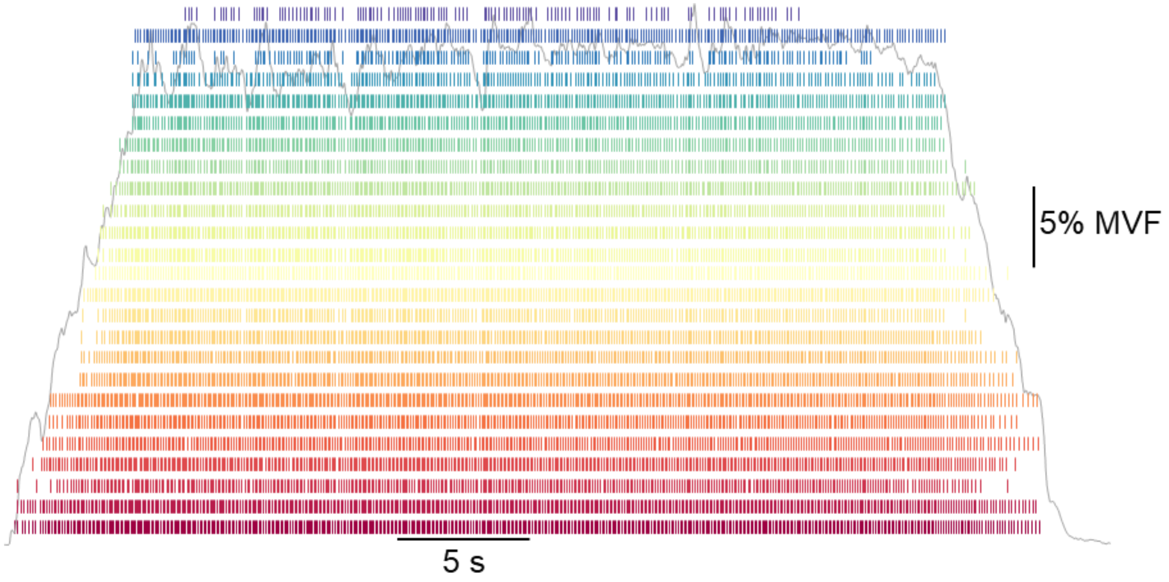
PART 1 – RECAP

- Motor unit discharge rate should be quantified through the lens of the experimental context
  - Be mindful of selecting the epoch (spike frequency adaptation)
  - Recruitment threshold is a likely covariate to discharge rate quantification that should be considered

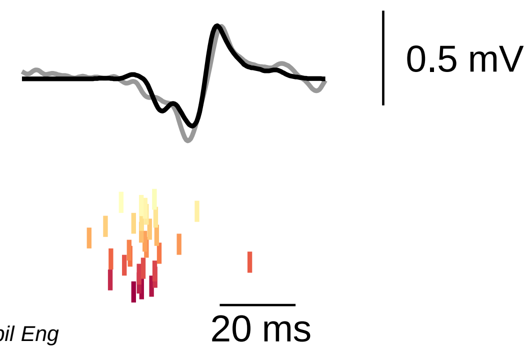
- Motor unit discharge rate is non-linearly related to excitation – action of persistent inward currents (PIC)
  - The effect of PICs, i.e. amplification and prolongation, may be quantified with a geometric analysis (acceleration) and a paired motor unit analysis (prolongation)
  - Be mindful of the types of inputs that may influence these metrics (as well as the experimental protocol/conditions/sample population)

Questions / break / continue?

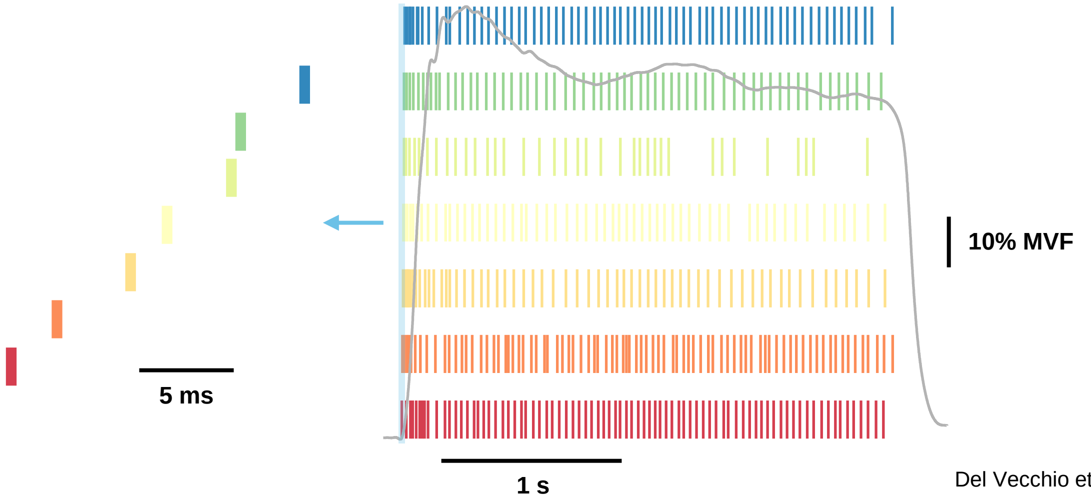
HDsEMG decomposition – Asynchronous vs. synchronous firing



Evoked contractions



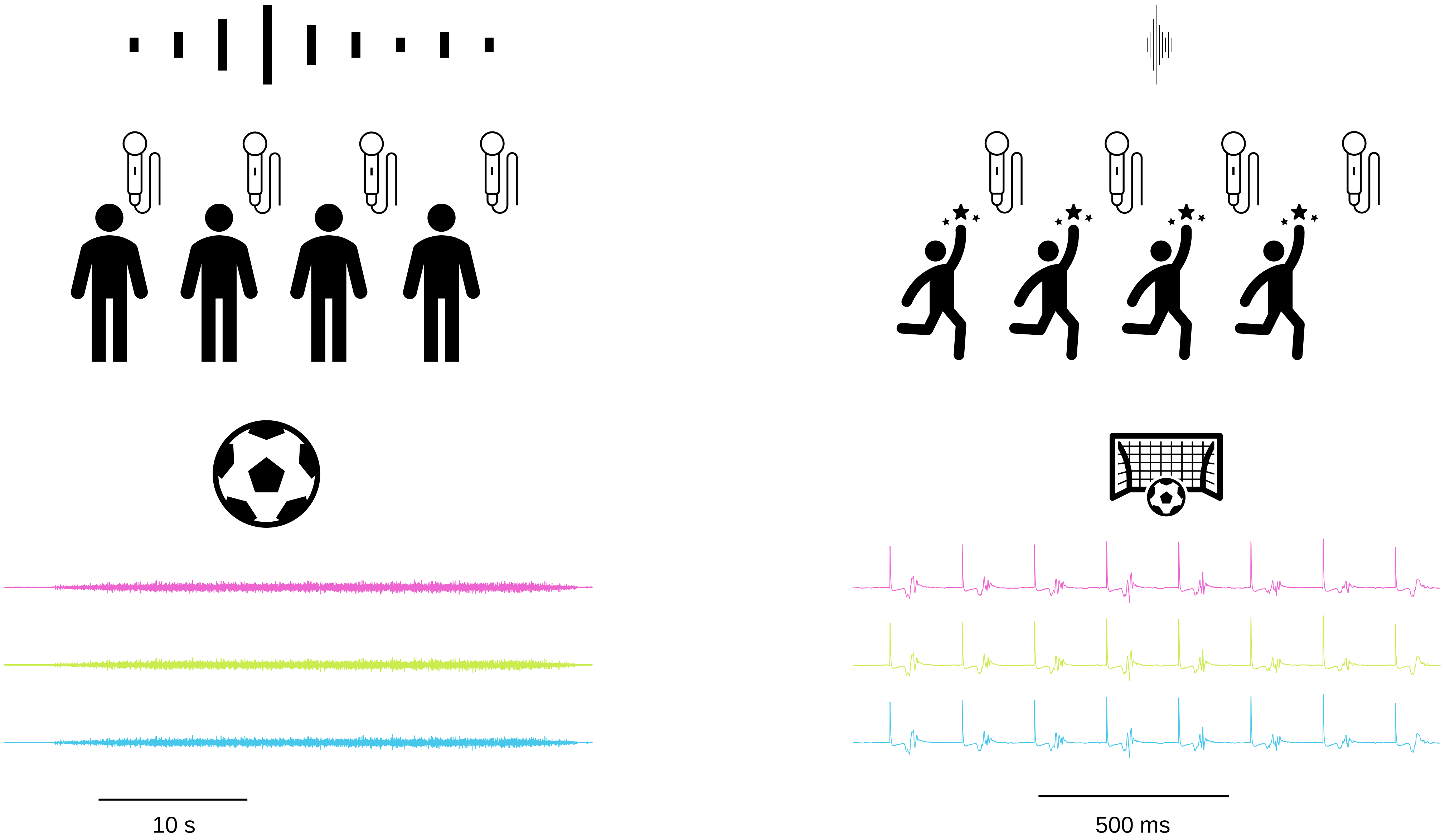
Rapid (isometric) contractions



Kalc et al. 2023, *IEEE Trans Neural Syst Rehabil Eng*
Kalc et al. 2023, *IEEE Trans Bomed Eng*
Škarabot et al. 2023, *J Physiol*
Del Vecchio et al. 2019, *J Physiol*

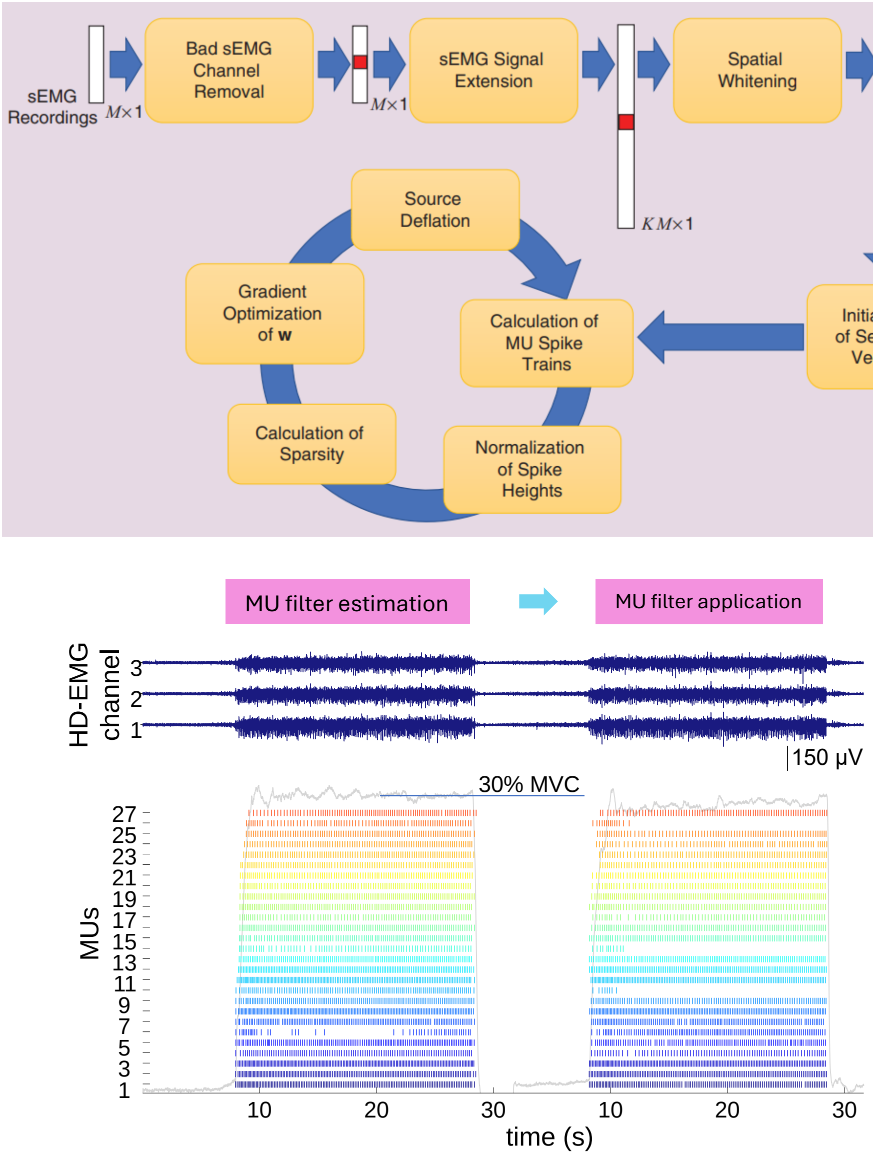
PART 2

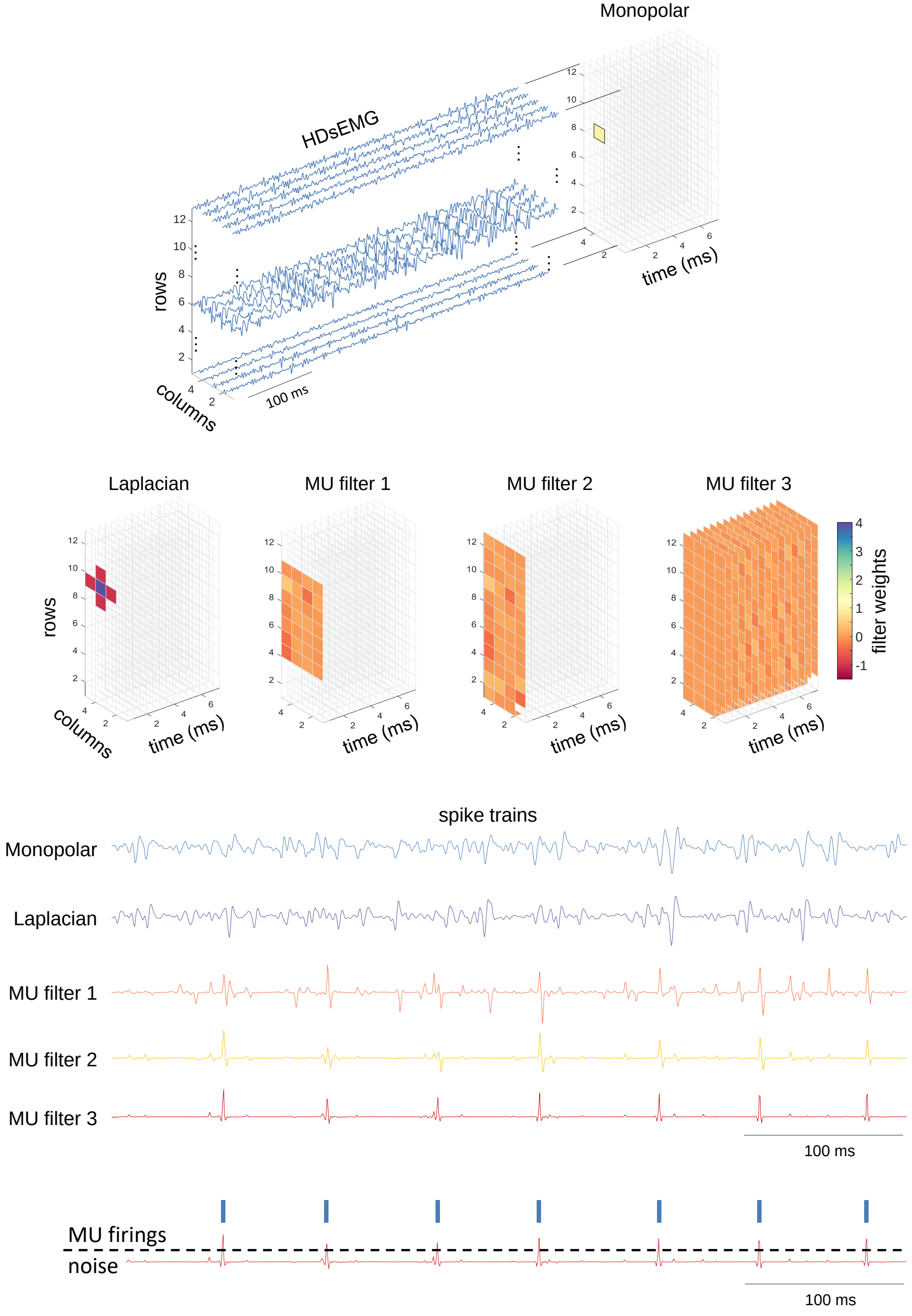
- Identification of motor unit discharges during evoked contractions
- Challenges in estimating motor unit recruitment thresholds in conditions of a compressed motor unit recruitment range
- Quantification of motor unit discharge behaviour during voluntary rapid contractions and maximal efforts



10 s
500 ms

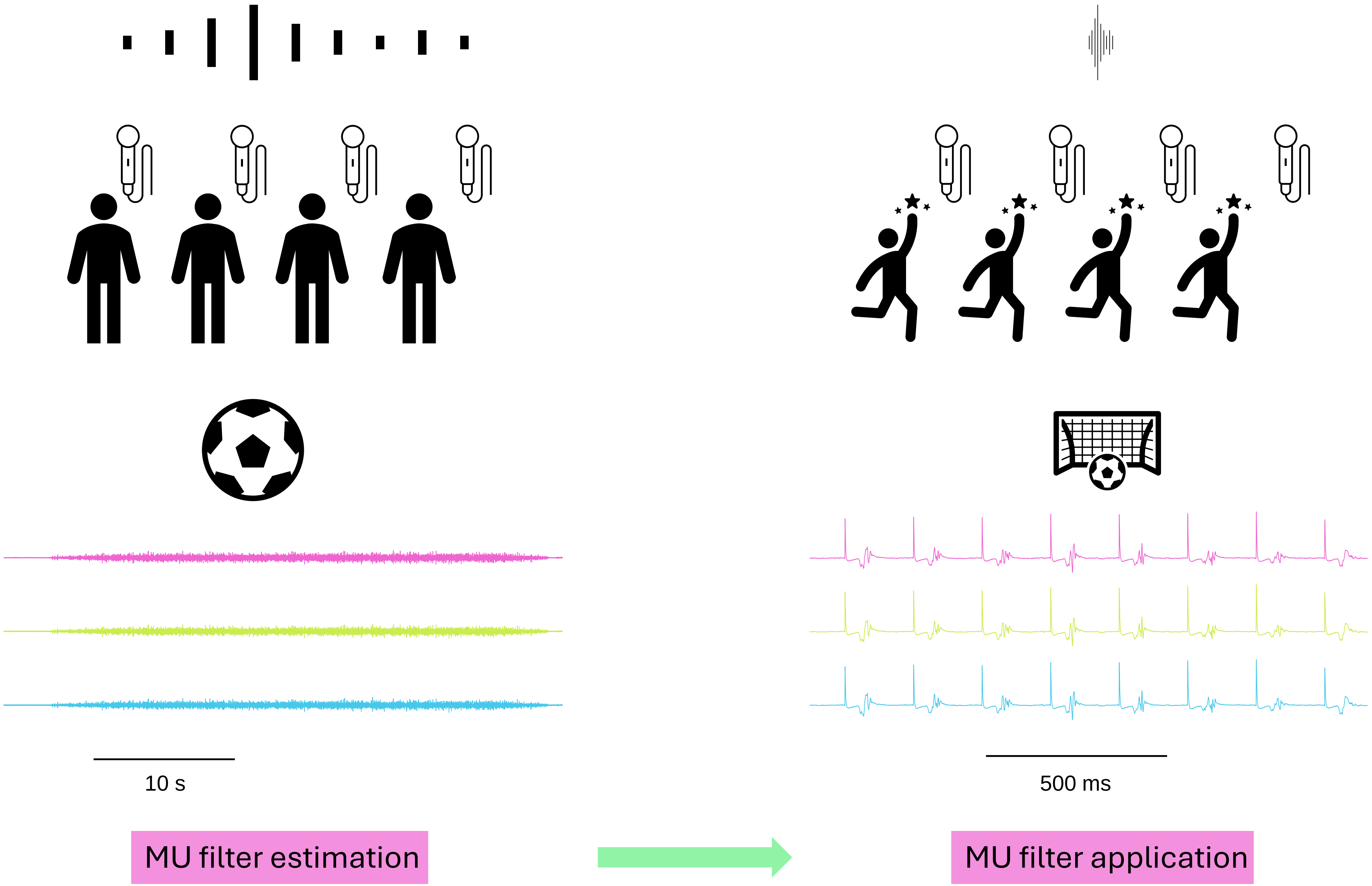
Separation vectors – MU filters



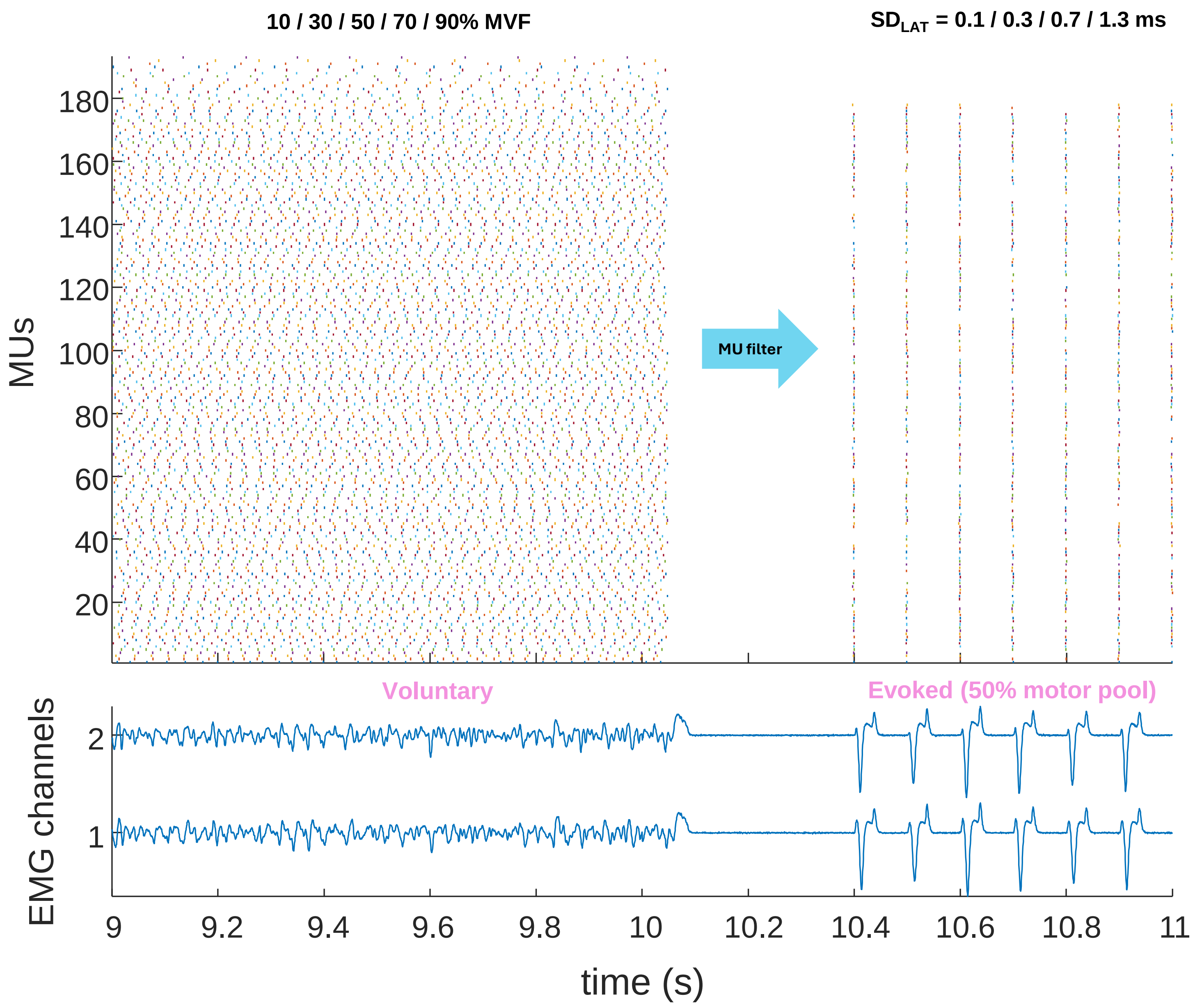


Holobar & Farina 2021, *IEEE Signal Process Mag*

Škarabot et al. 2023, *J Physiol*

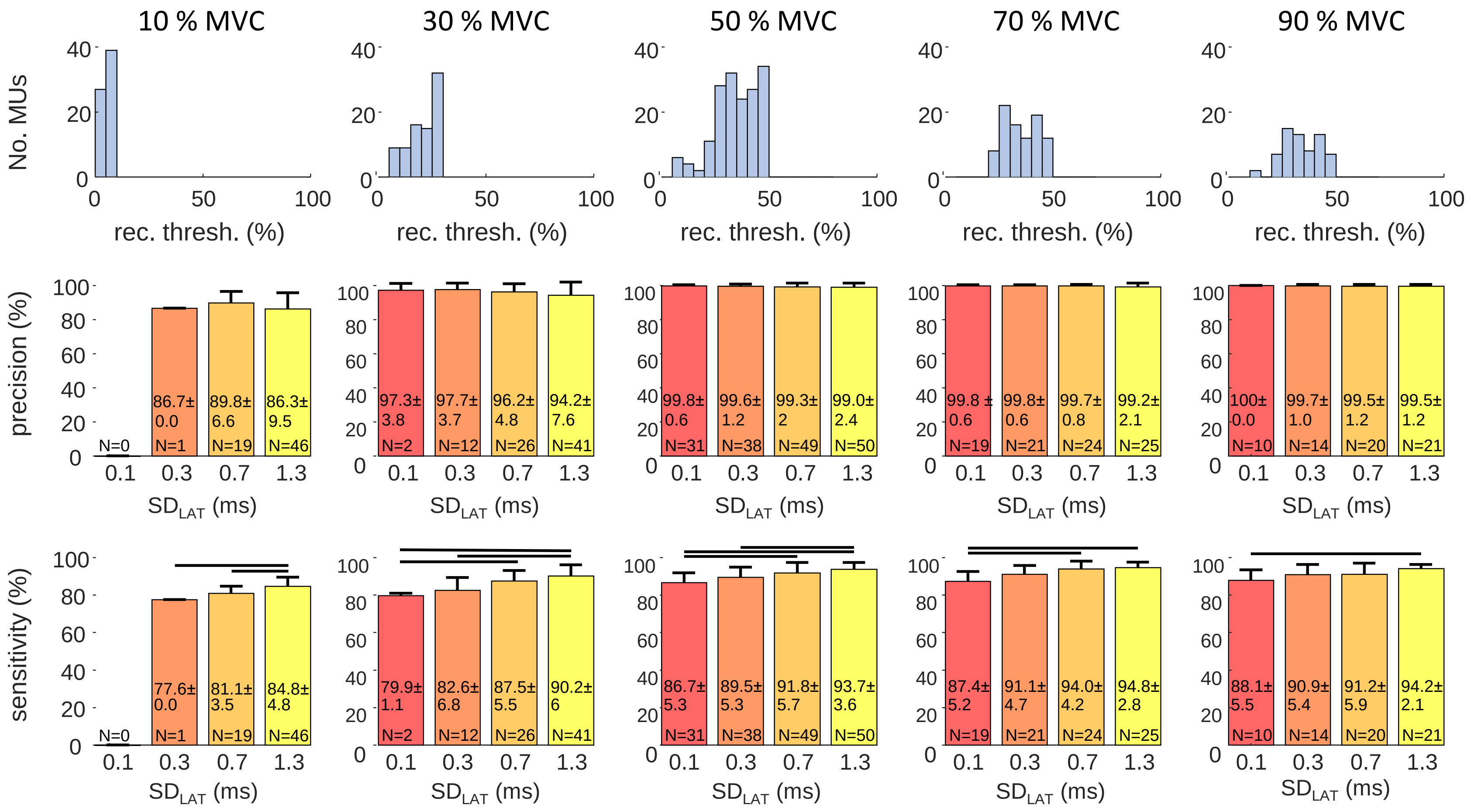

10 s
500 ms
MU filter estimation
MU filter application

MU identification during high synchronisation levels



Kalc et al. 2023, *IEEE Trans Biomed Eng*

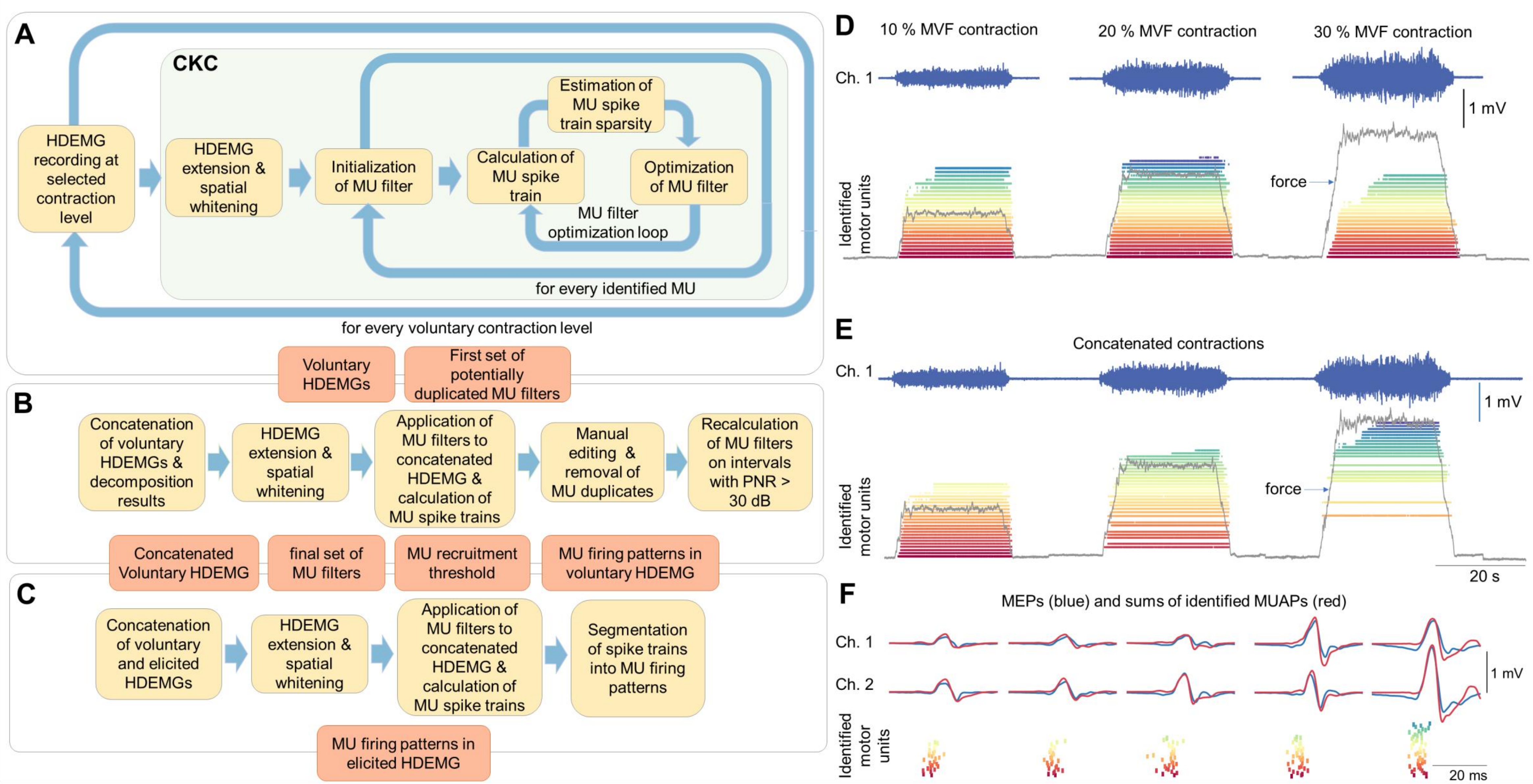
MU identification during varying synchronisation levels



- No identified MUs with recruitment threshold >50% MVC → likely low # false negatives
- High levels of precision throughout.
- Comparatively lower sensitivity, indicating some firings might be missed.

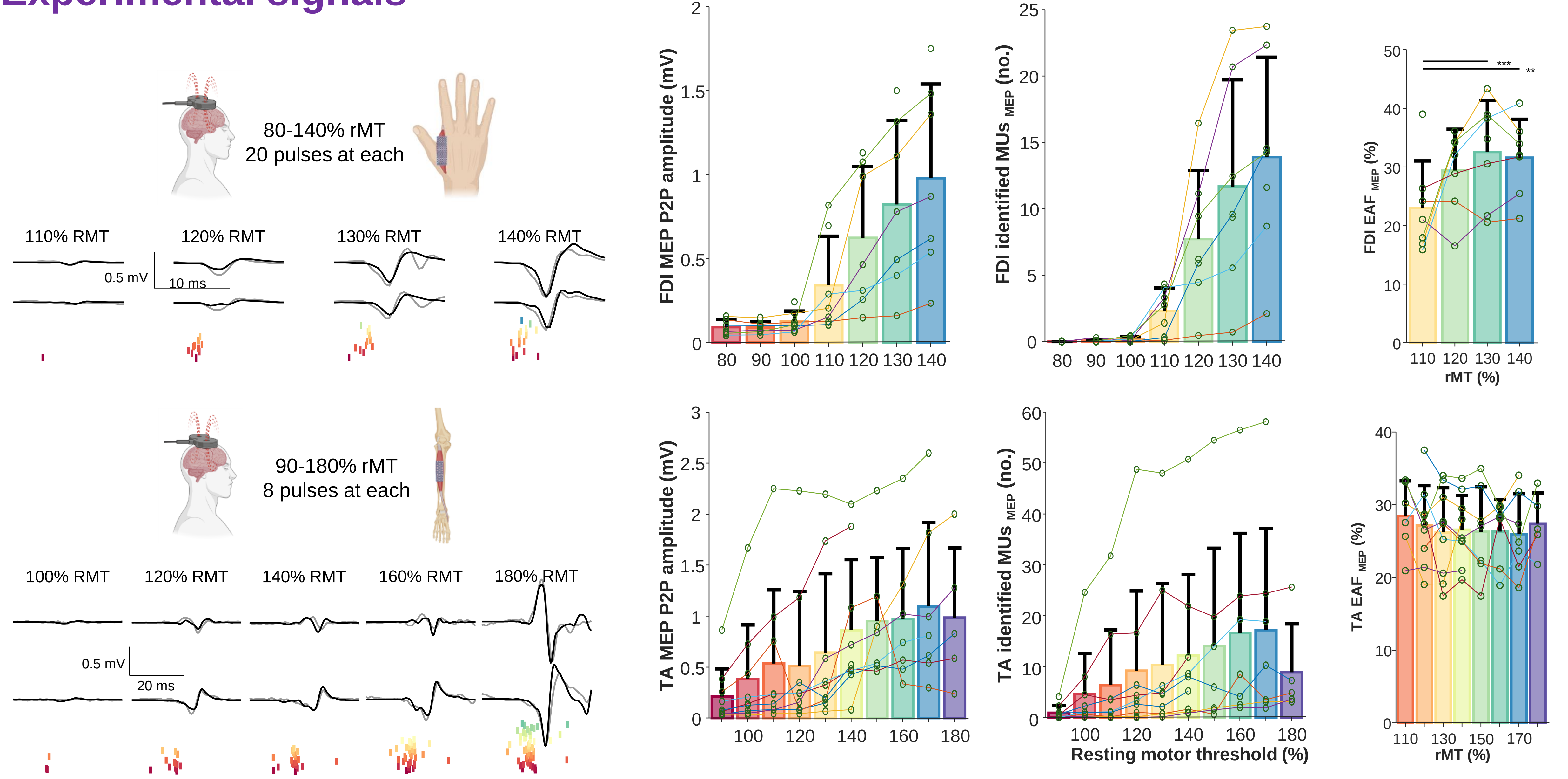
Kalc et al. 2023, *IEEE Trans Biomed Eng*

Identification of MU firings during evoked contractions – the pipeline



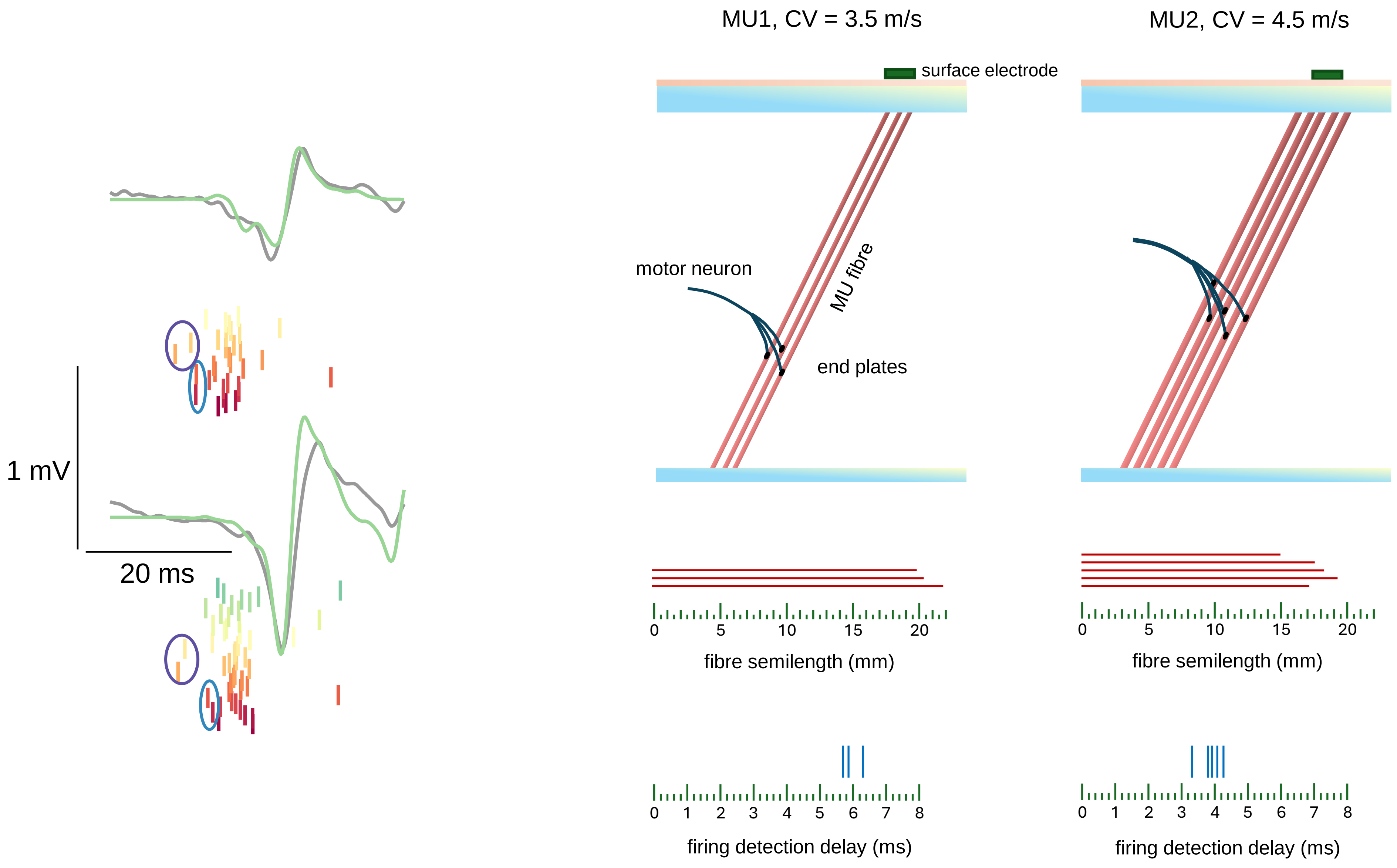
Škarabot et al. 2023, *J Physiol*

Experimental signals



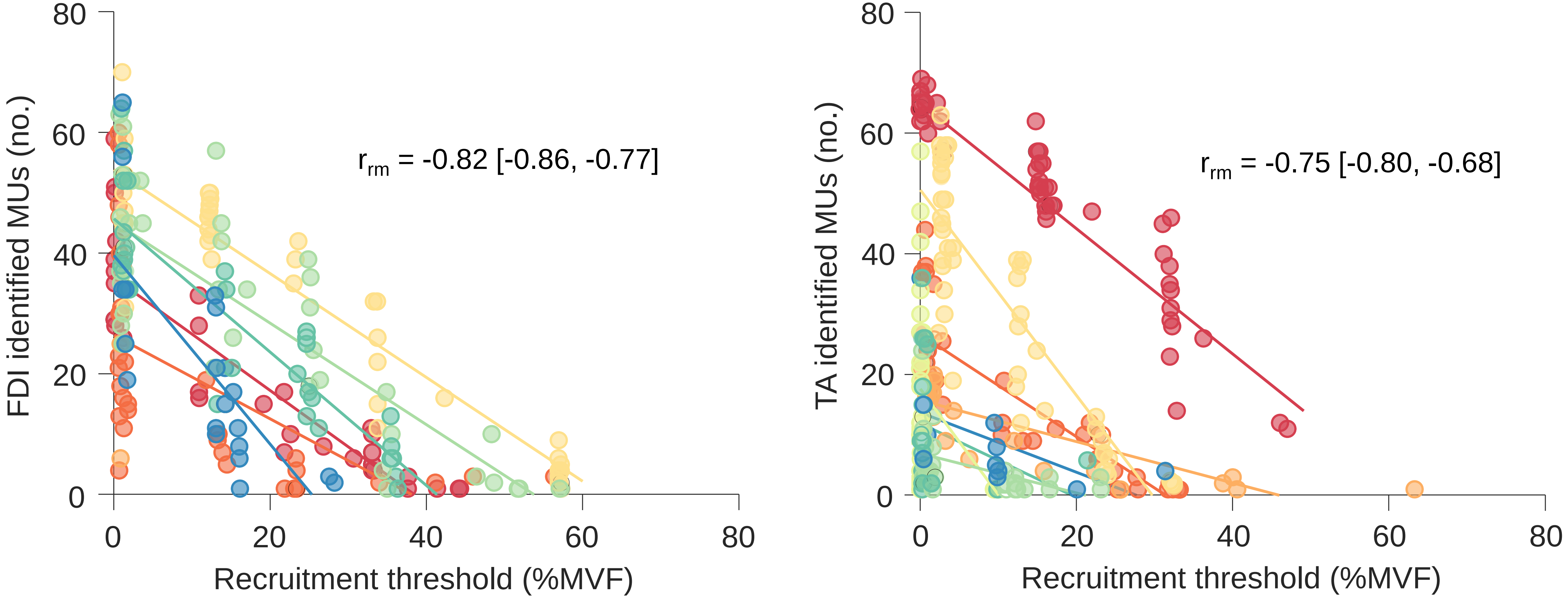
Škarabot et al. 2023, *J Physiol*

Estimation of recruitment threshold

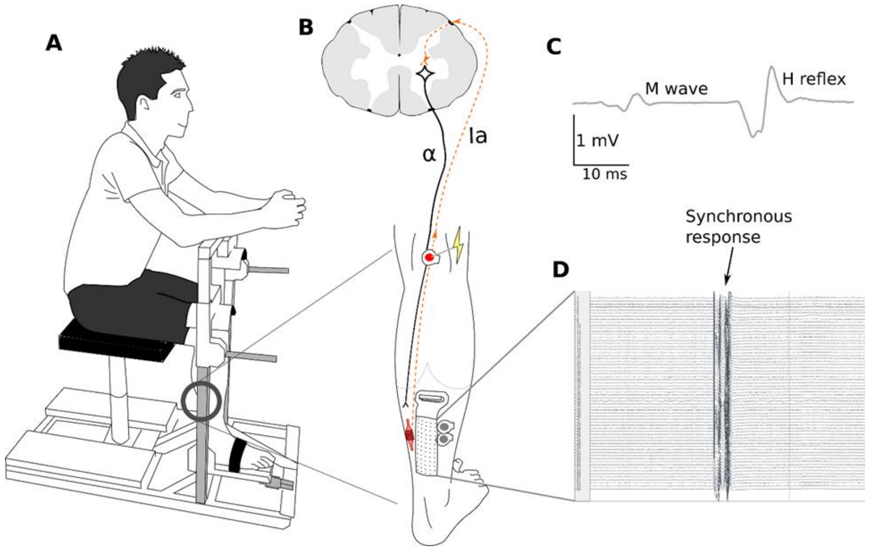


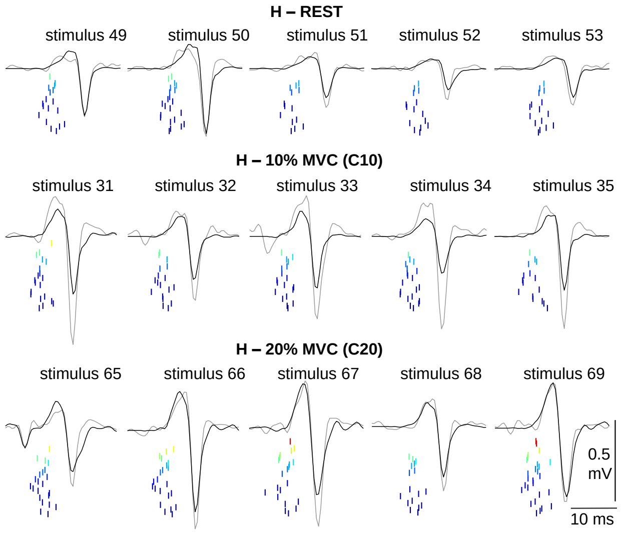
Škarabot et al. 2023, *J Physiol*

Recruitment order

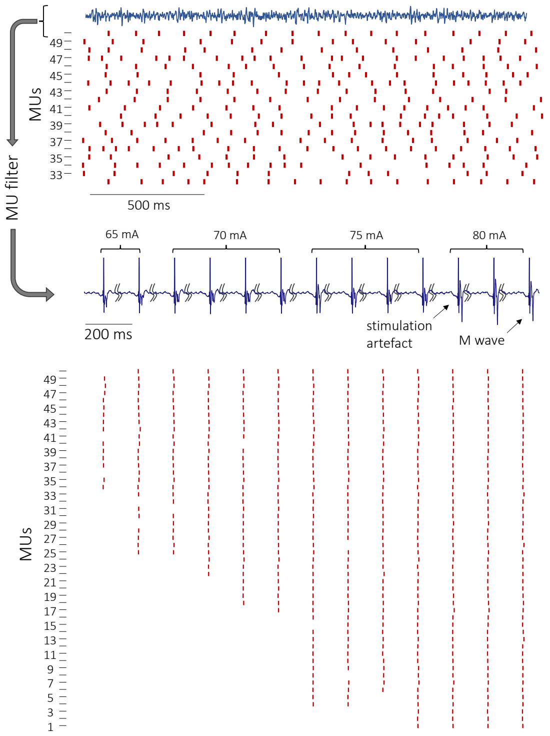


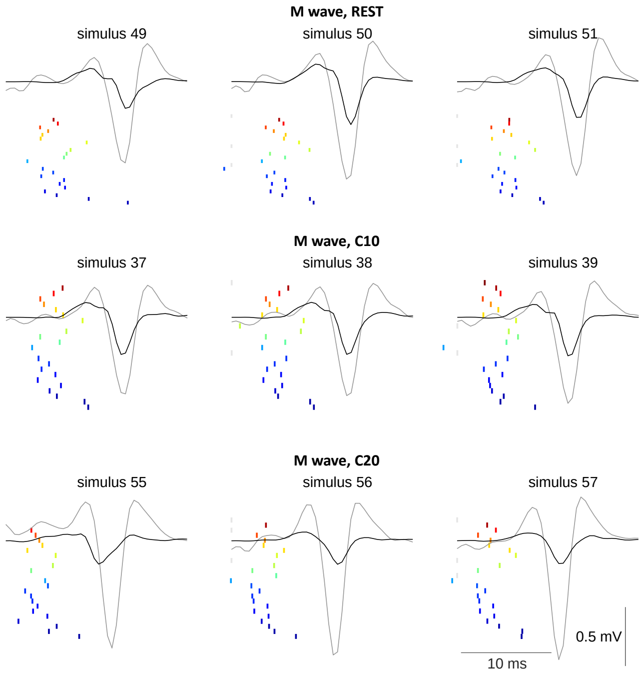
Škarabot et al. 2023, *J Physiol*





Kalc et al. 2023, *IEEE Trans Neural Syst Rehabilitation Eng*





Kalc et al. 2023, *IEEE Trans Biomed Eng*

Identification of MU firings during evoked contractions from surface EMG

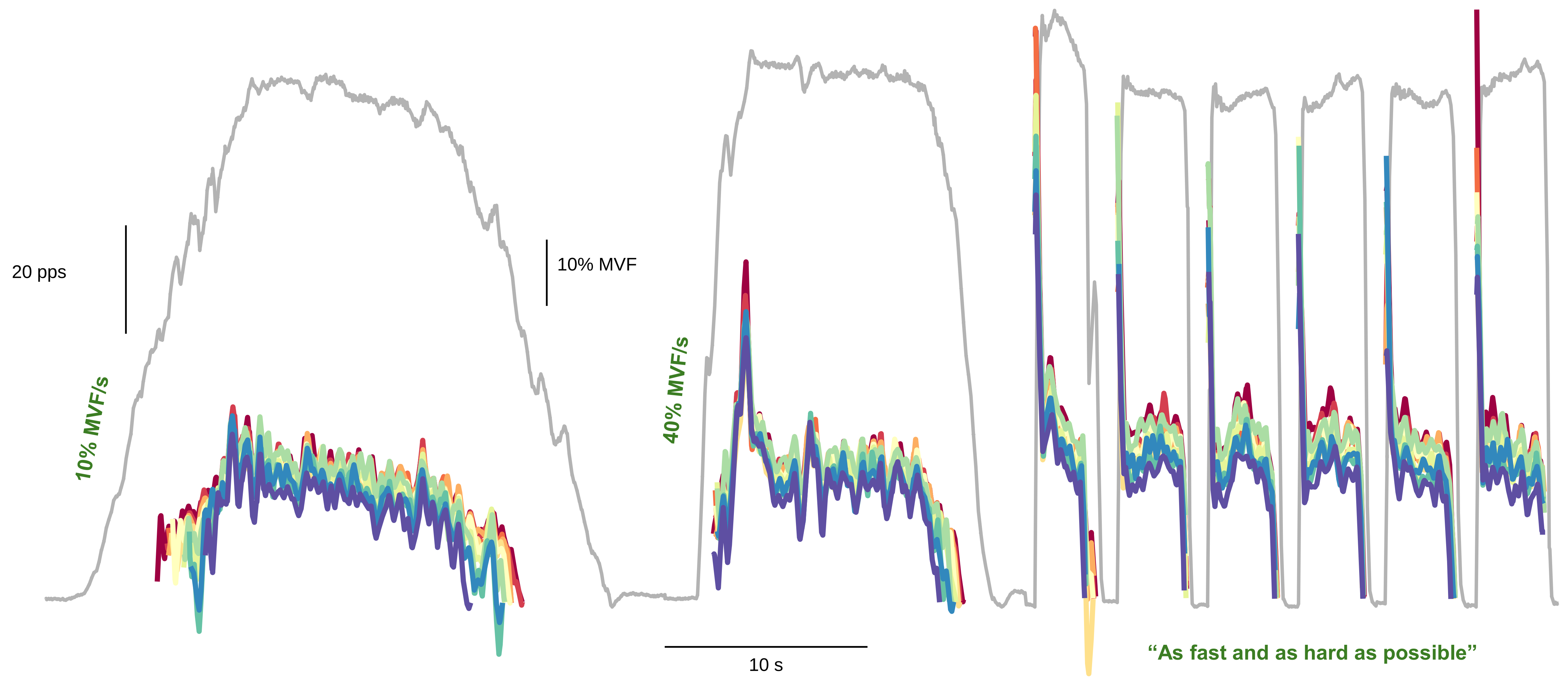
STRENGTHS

- Non-invasive investigation of responses to TMS at the level of single MUs
- Many identified MUs (wide recruitment range)
- Fewer stimuli needed
- Possibility to track units?

WEAKNESSES

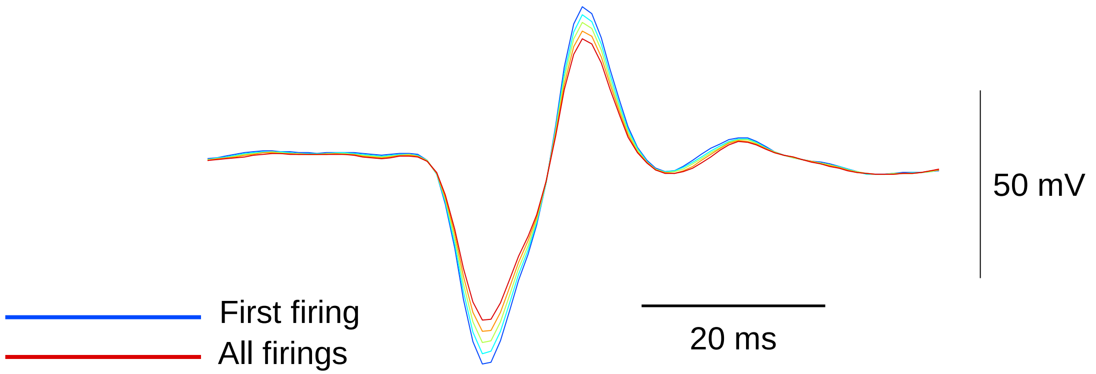
- Limited to MUs identified during voluntary efforts
- Limitations of HDsEMG decomposition with BSS still apply:
  - Inability to identify MUs further away from recording site
  - Difficulty in segmenting higher-threshold units due to superimposition of MUAPs
  - Inherent bias towards large MUs with large MUAPs

Feedback (ramp) vs. feedforward (rapid) contractions



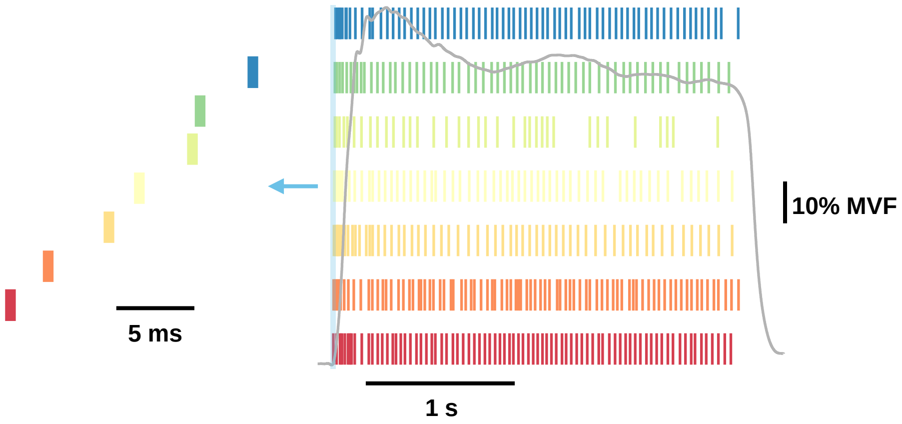
MU identification during rapid (isometric) contractions

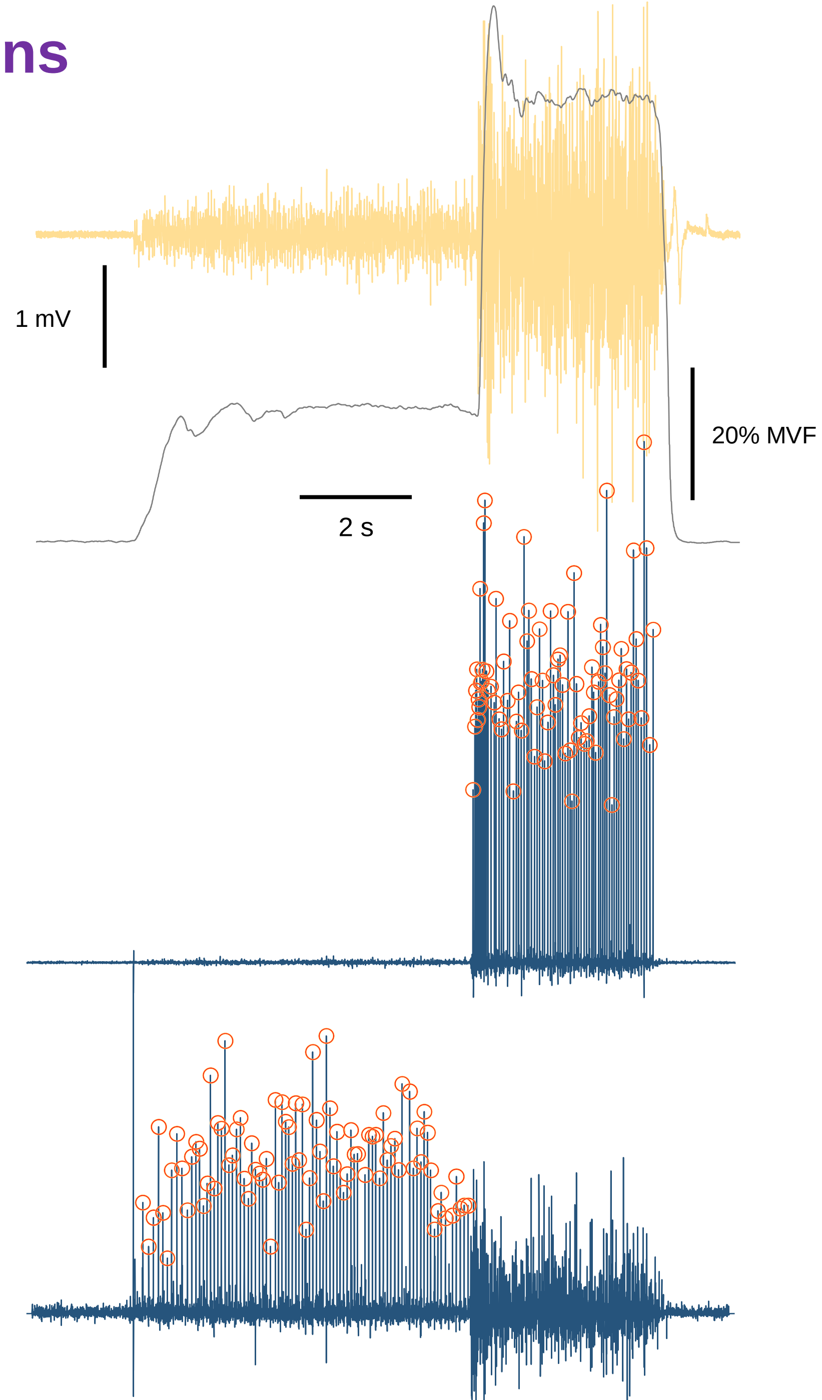
Challenge 1: The change in MUAP waveform



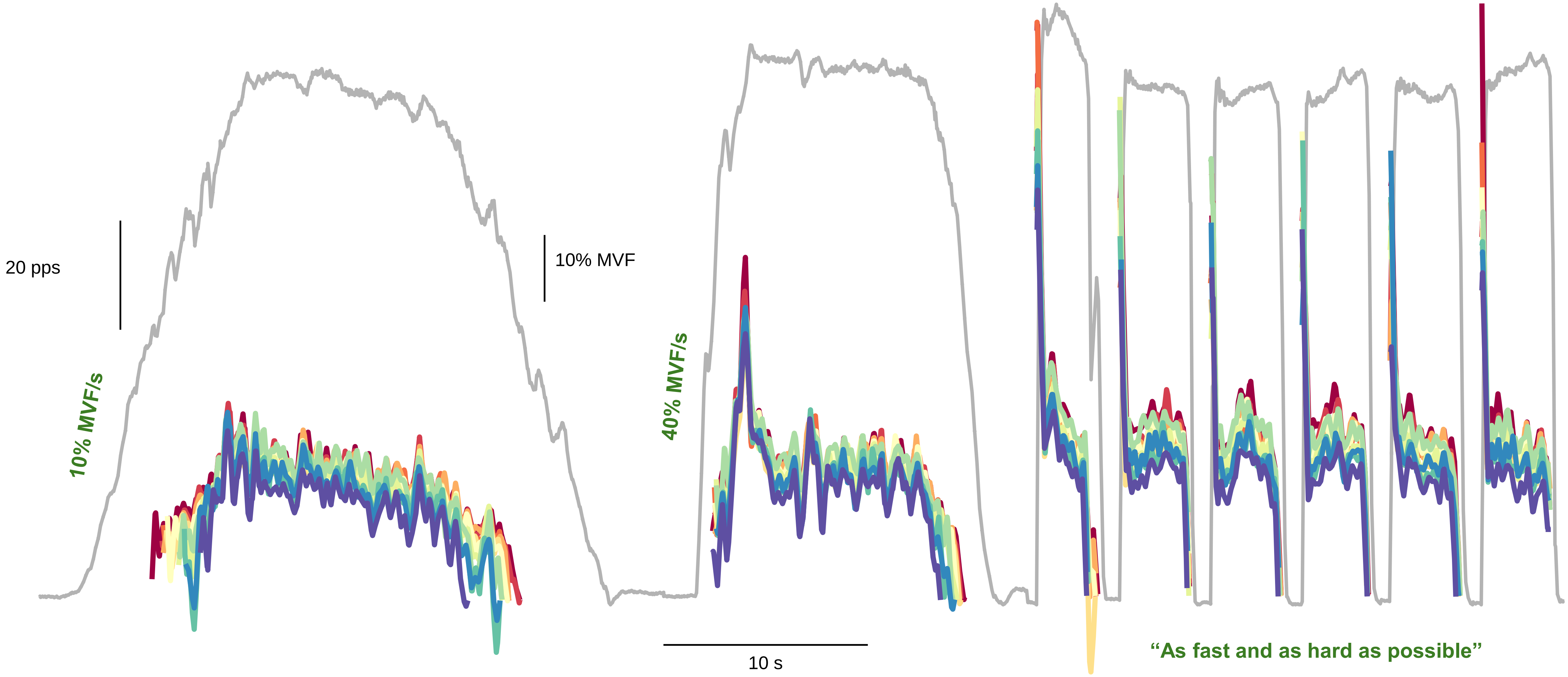
Challenge 2: Bias towards larger potentials

Challenge 3: Superimposition of MUAPs

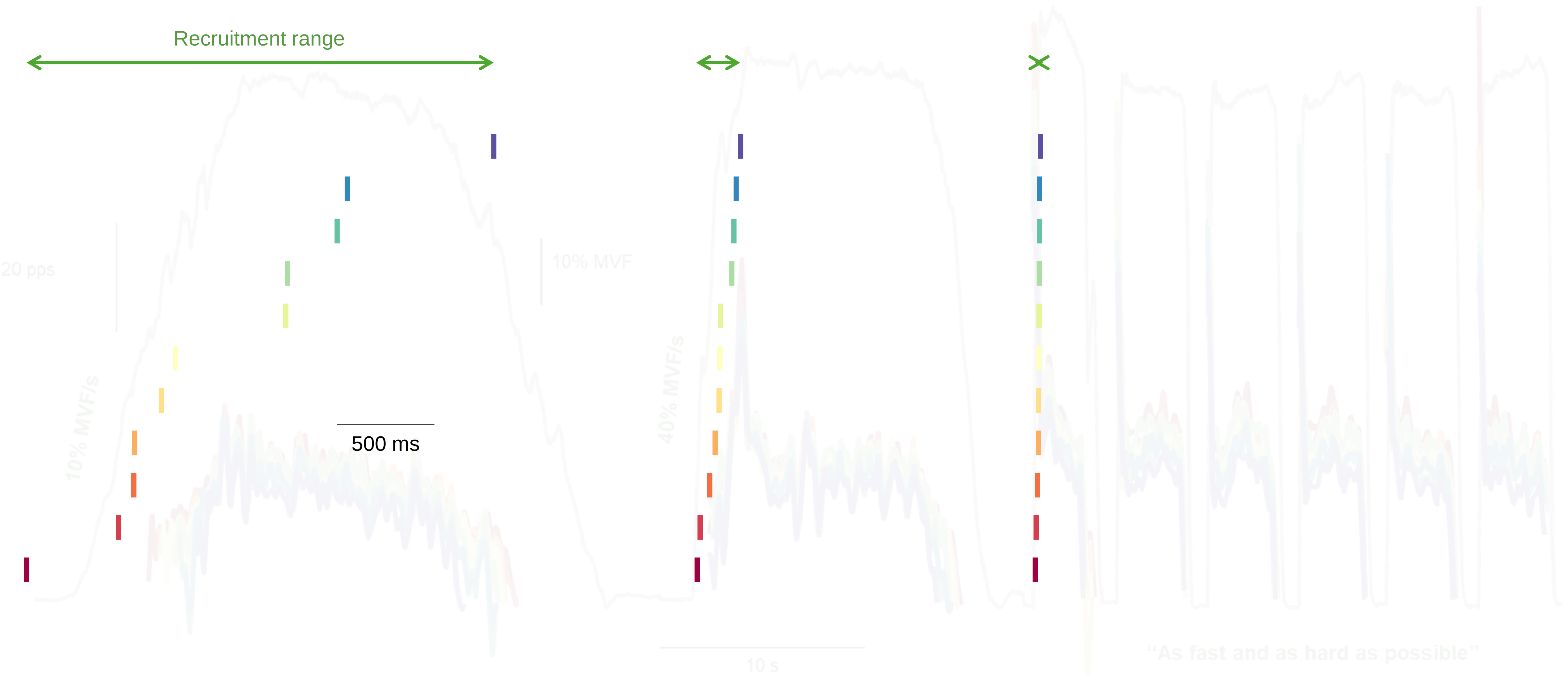




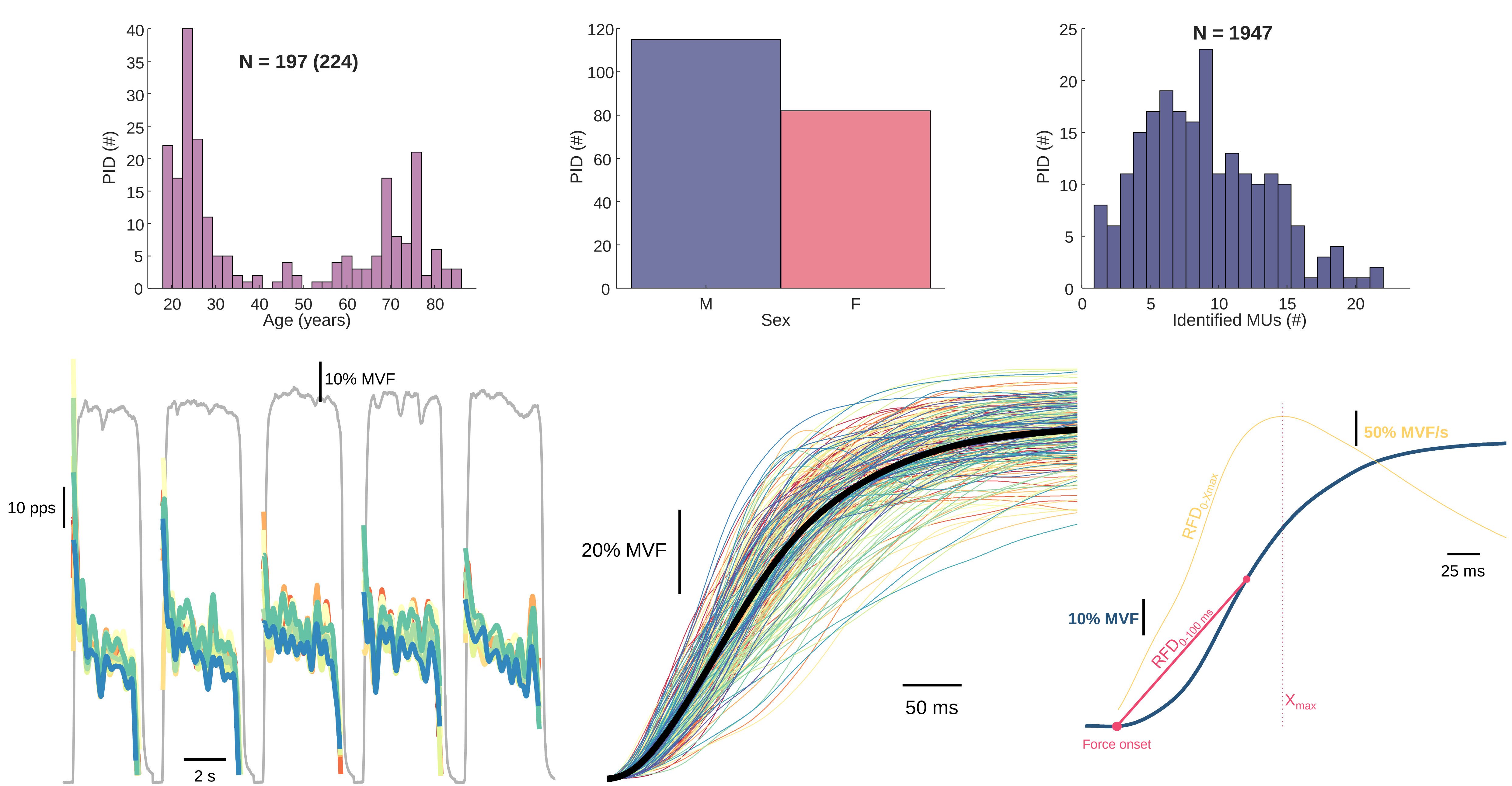
Feedback (ramp) vs. feedforward (rapid) contractions



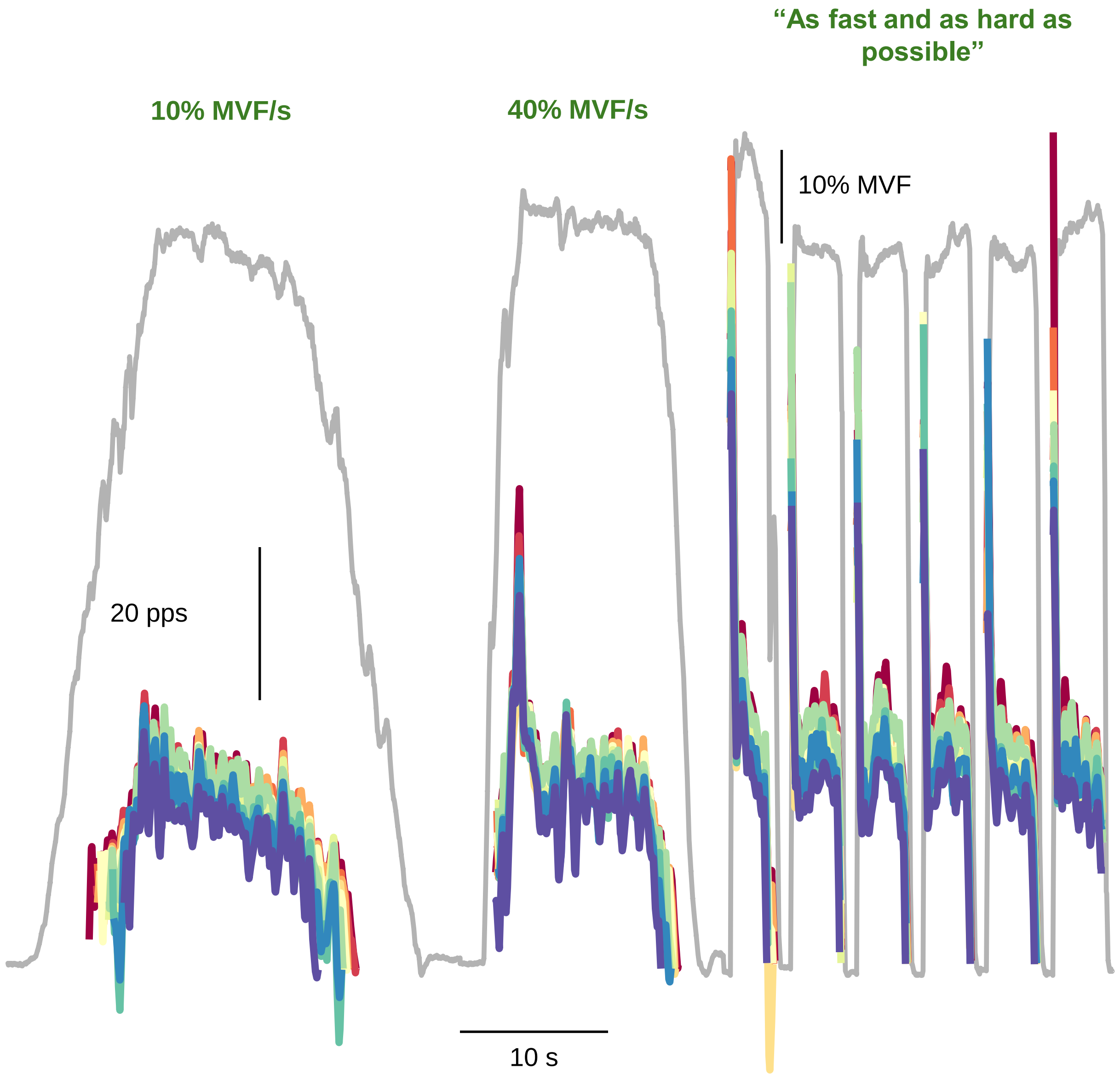
Feedback (ramp) vs. feedforward (rapid) contractions

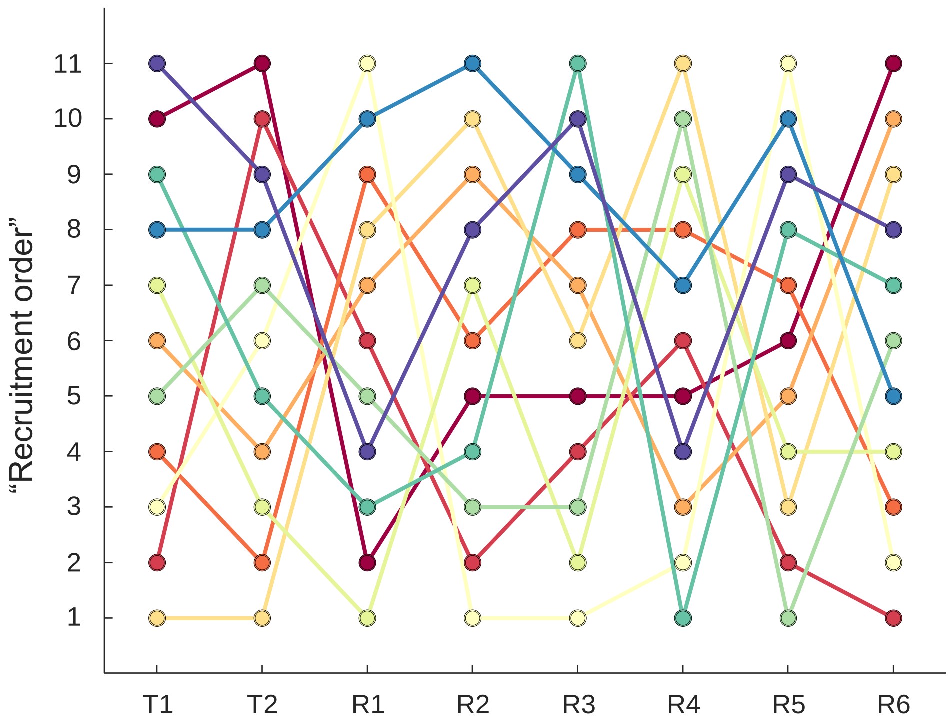


MU firing behaviour during rapid contractions

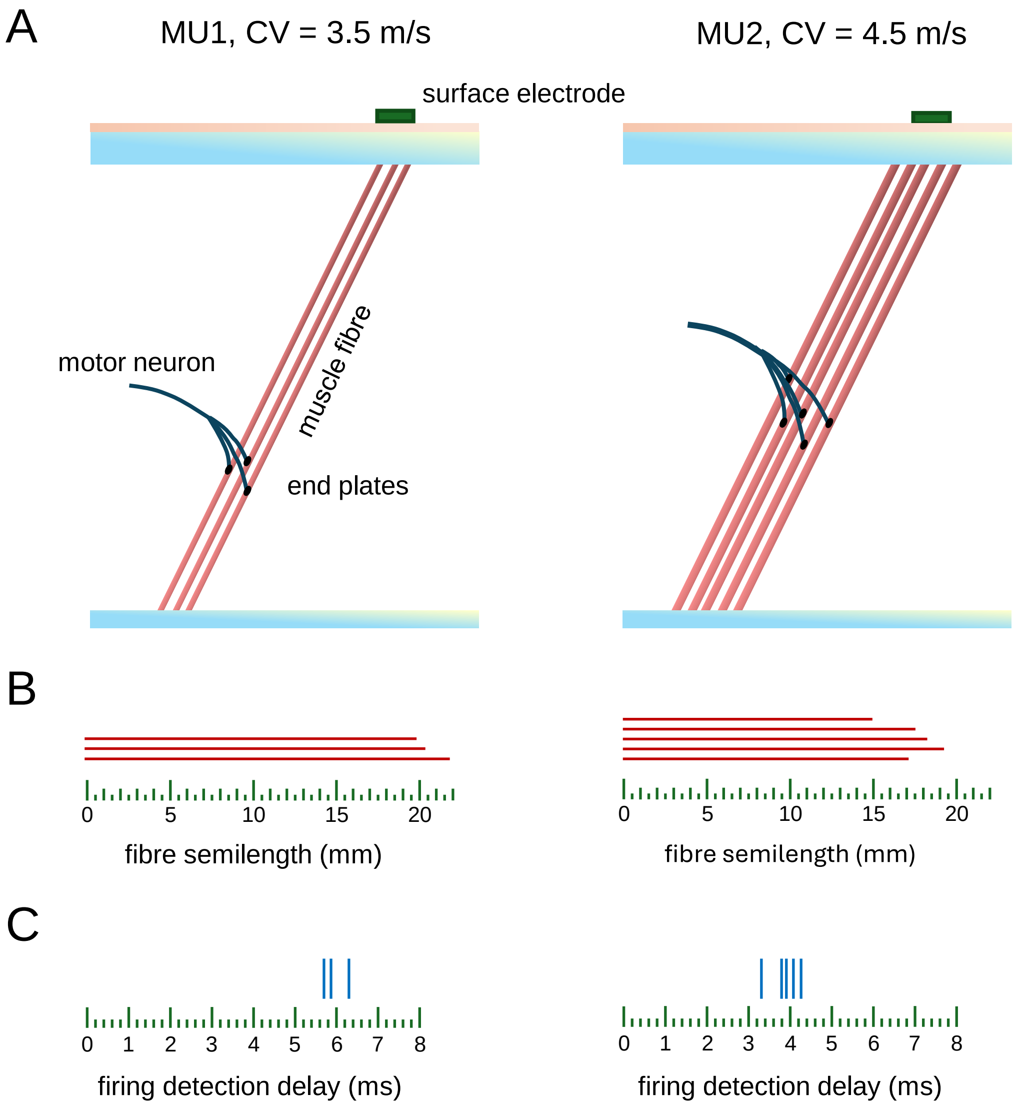


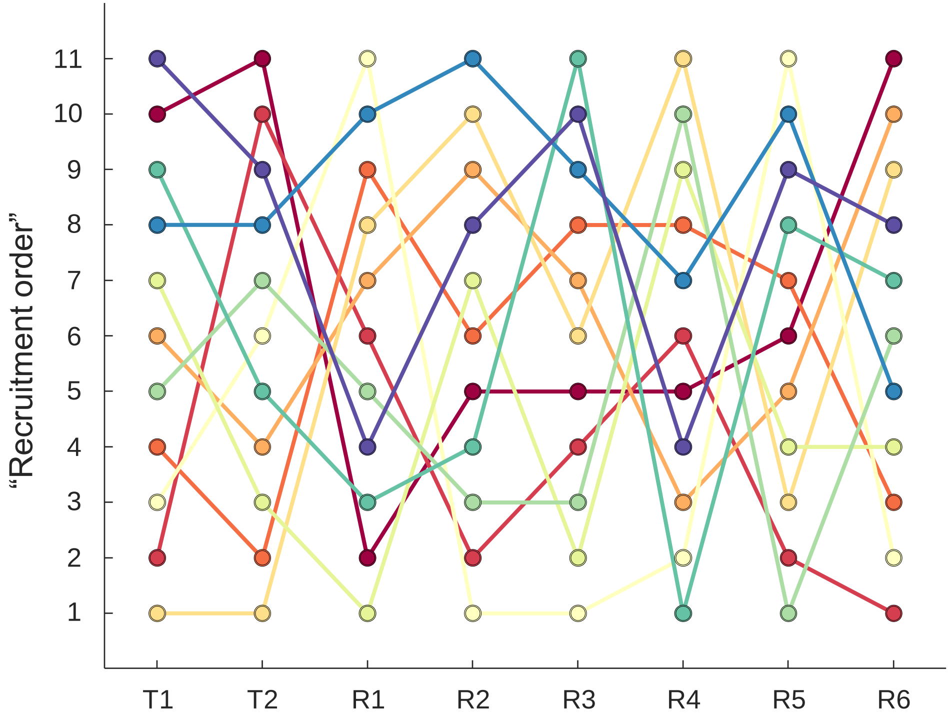
Motor unit recruitment order





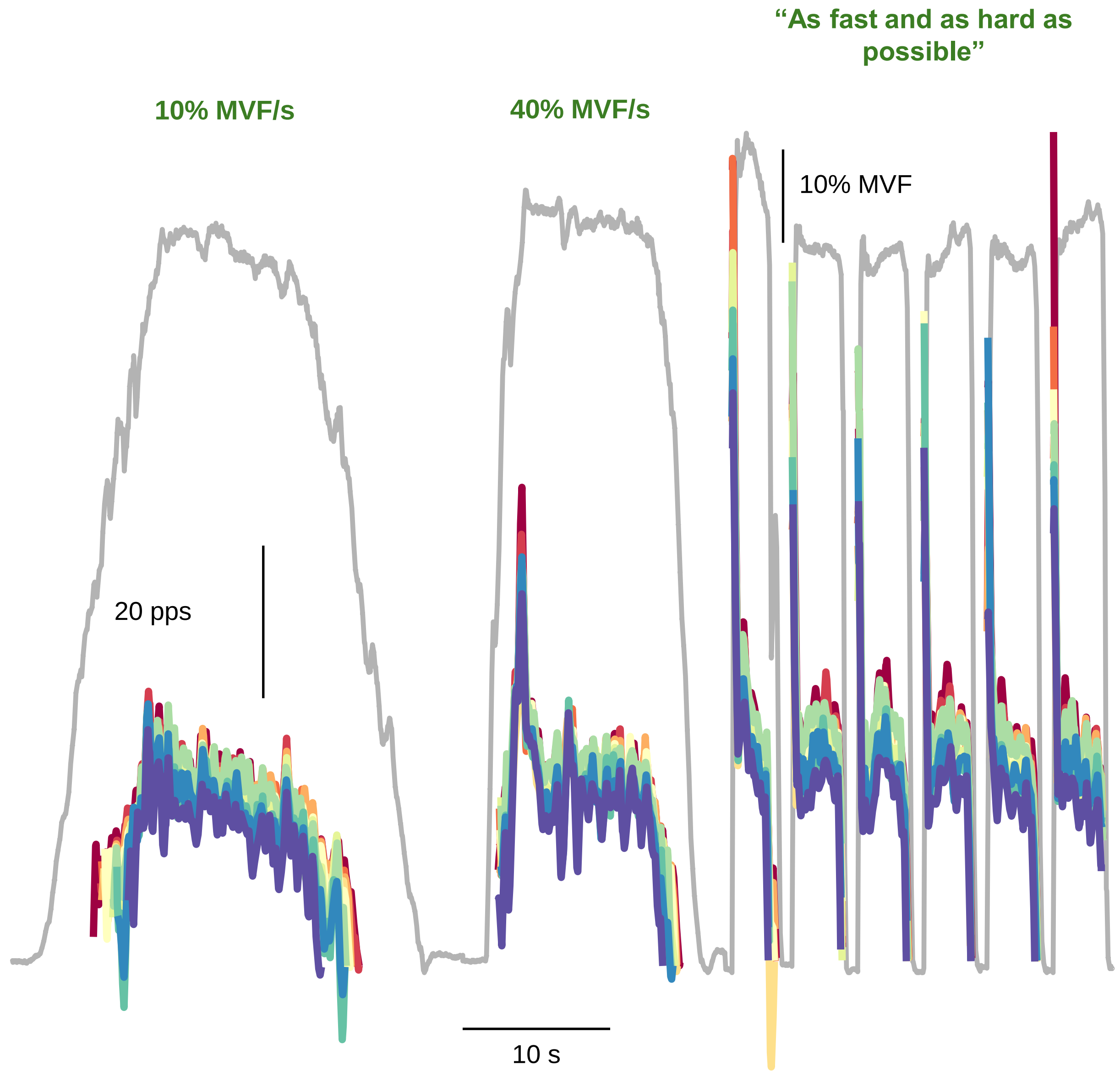
Motor unit recruitment order

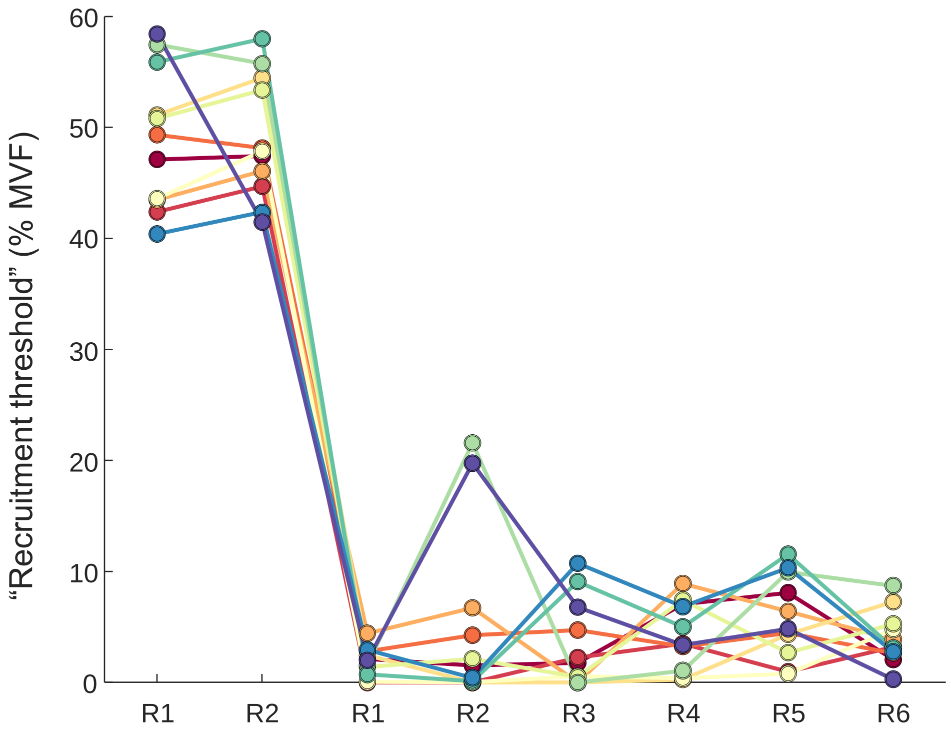




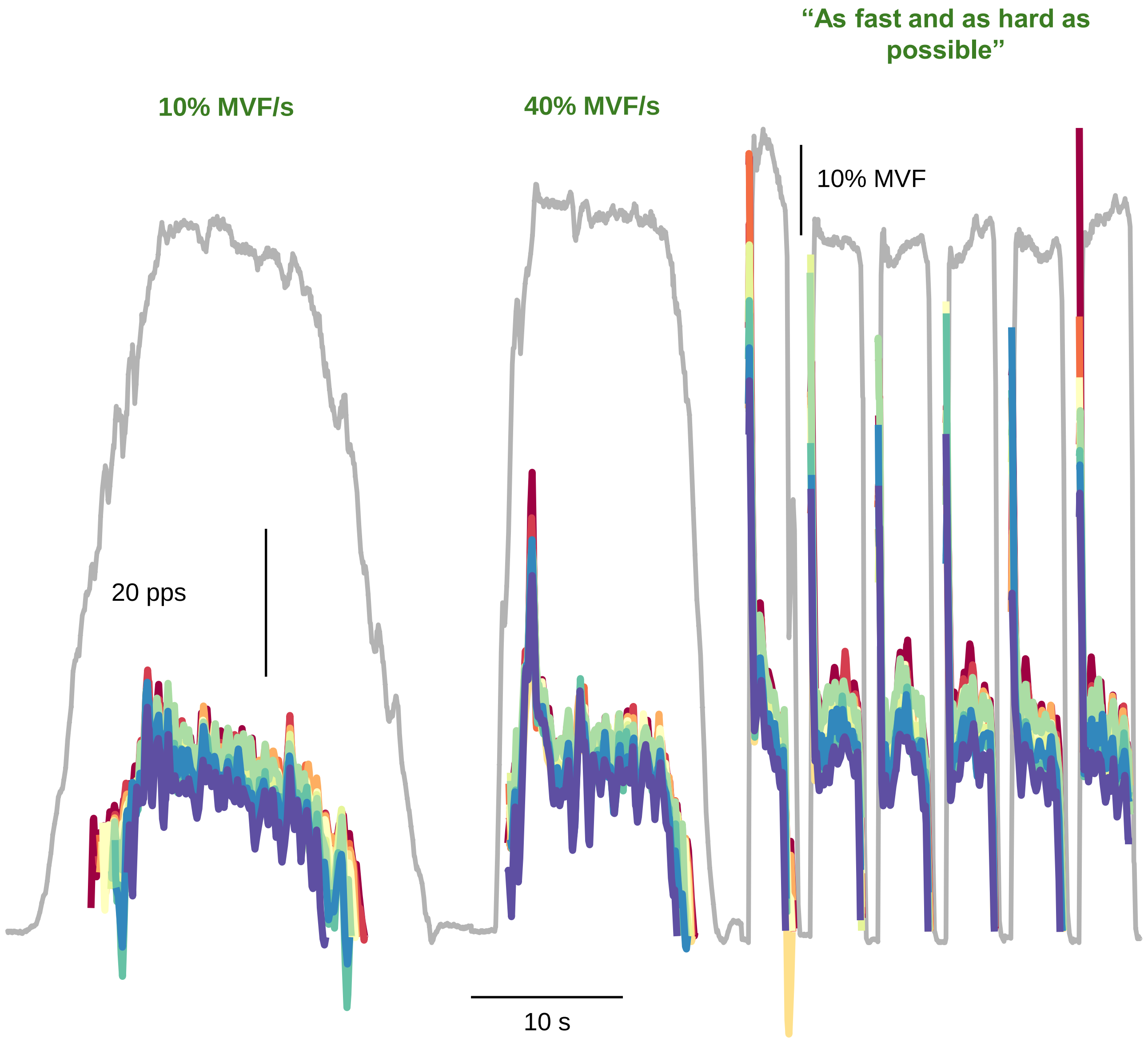
Škarabot et al. 2023, *J Physiol*

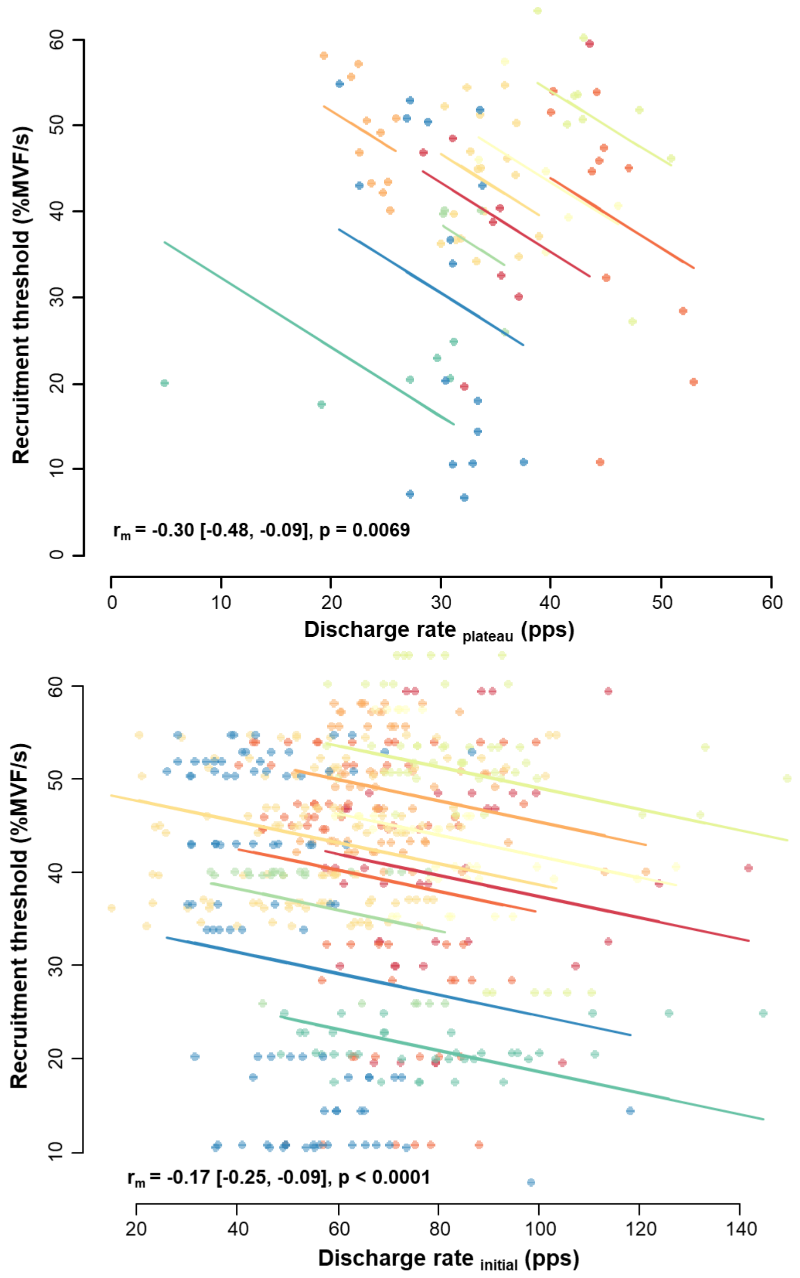
Motor unit recruitment threshold





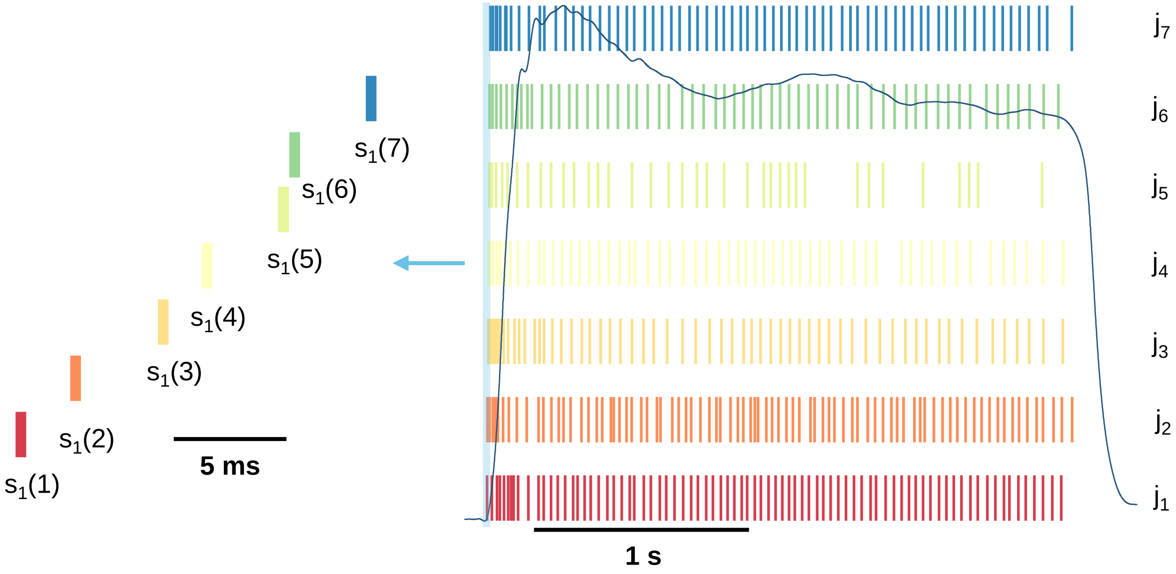
MU firing rate relative to recruitment threshold during rapid contractions

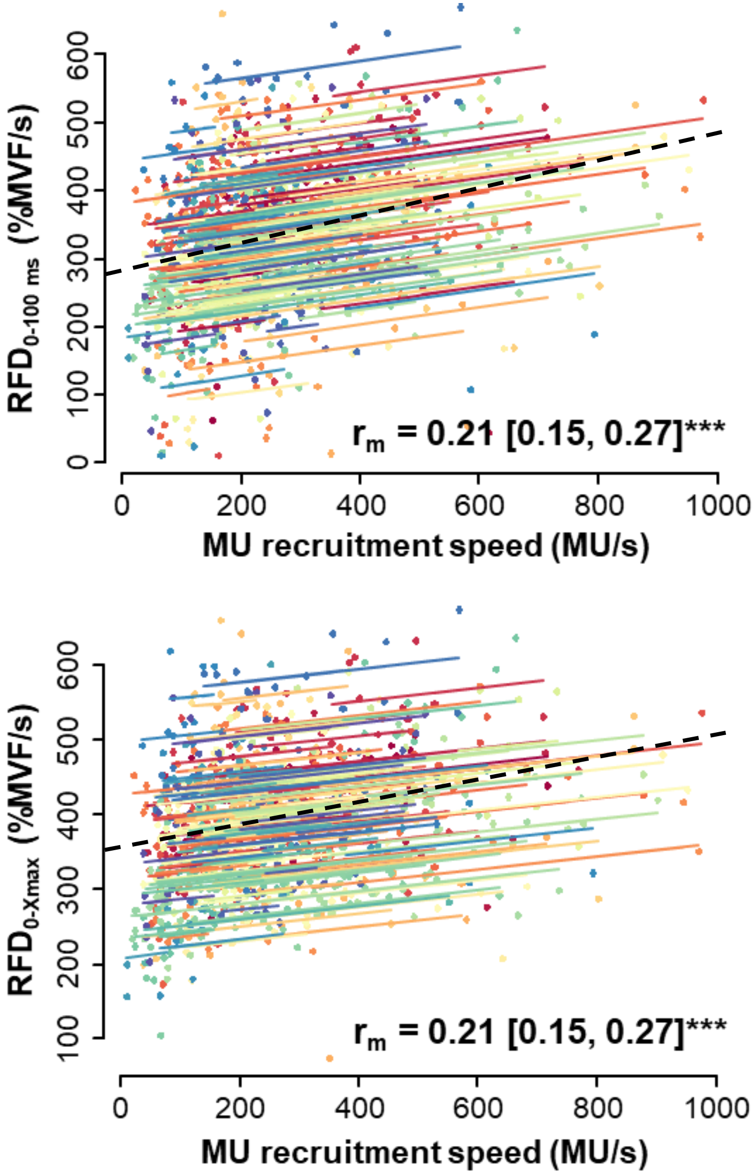




Motor unit recruitment speed

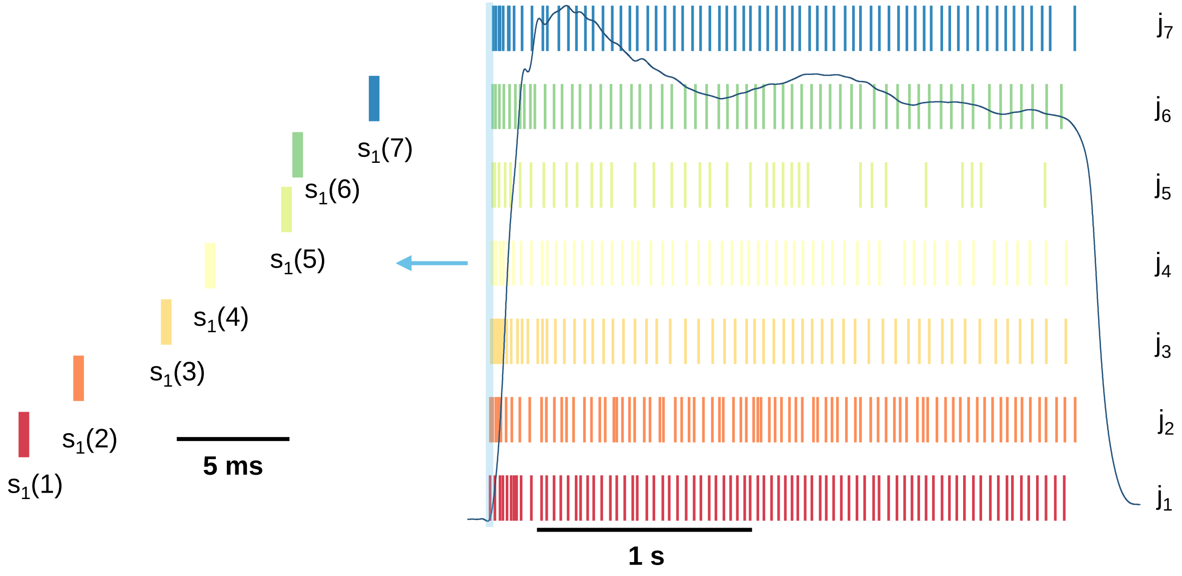
$$Recruitment\ speed = \frac{N-1}{\sum^{N-1}(s_1(j+1) - s_1(j))}$$

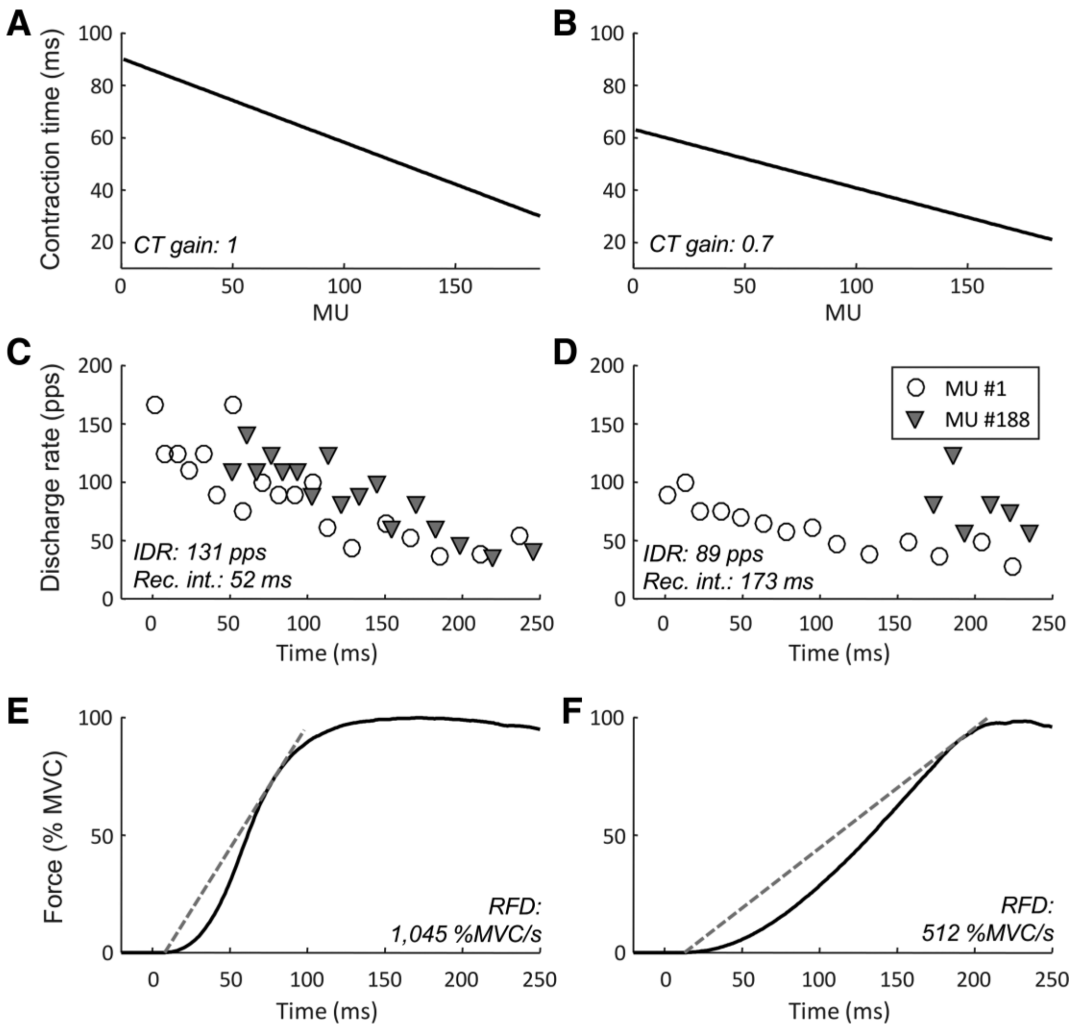




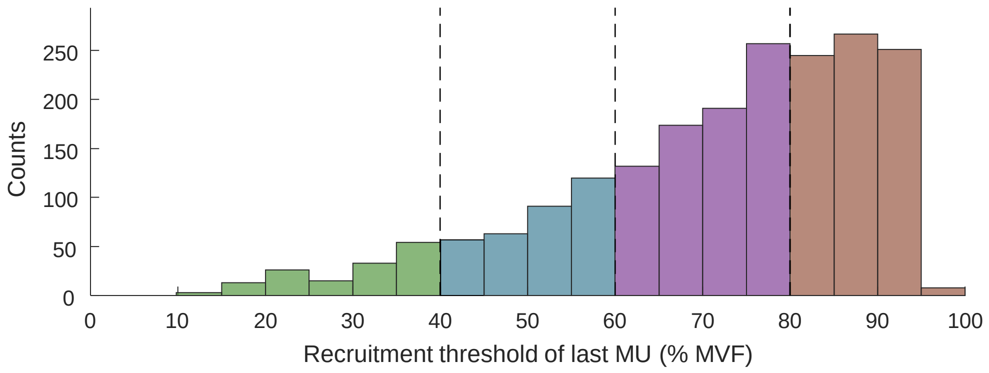
Motor unit recruitment speed

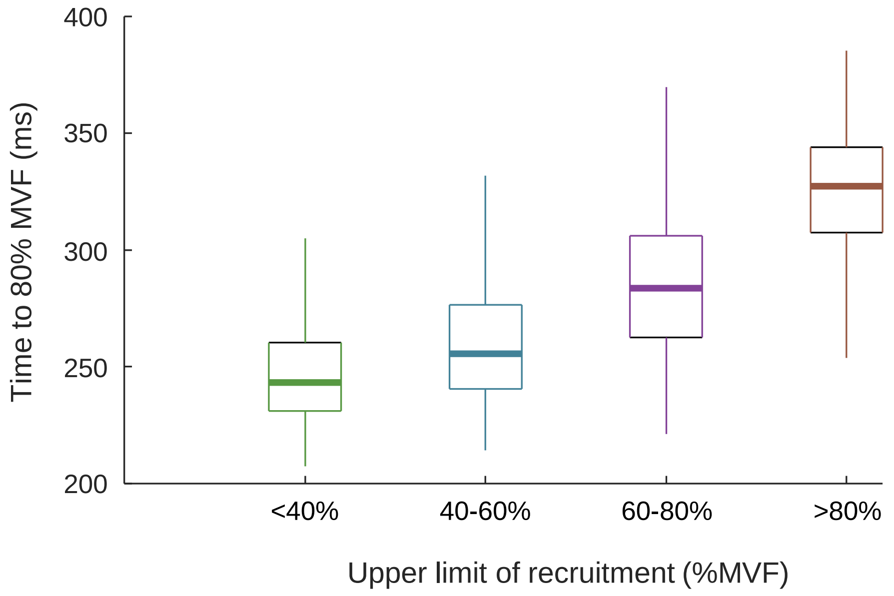
$$Recruitment\ speed = \frac{N-1}{\sum^{N-1}(s_1(j+1) - s_1(j))}$$

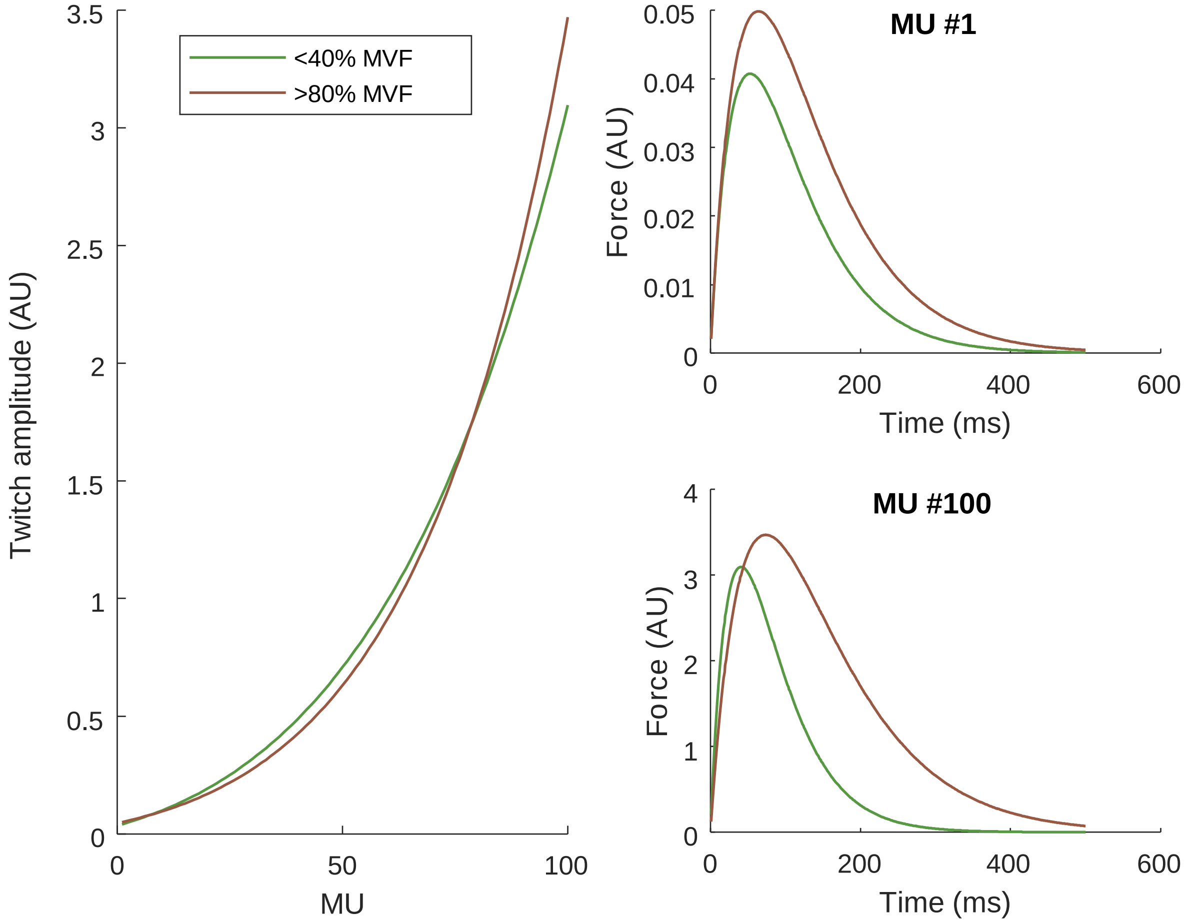




Motor unit recruitment speed as a function of the upper limit of recruitment

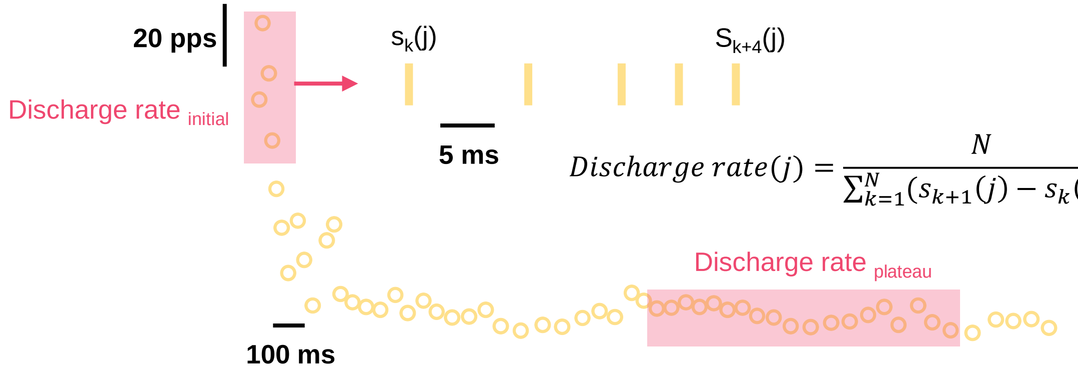




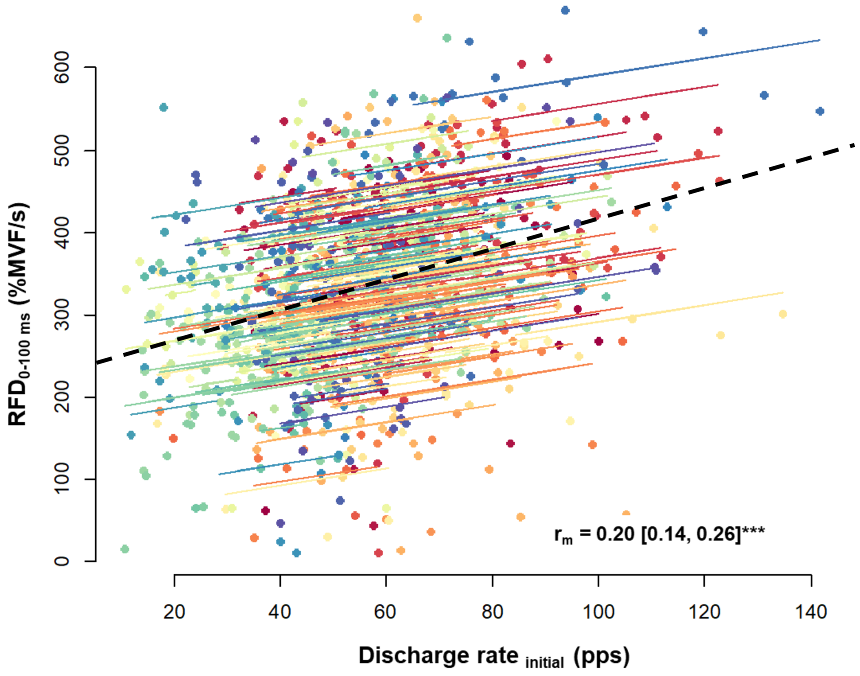


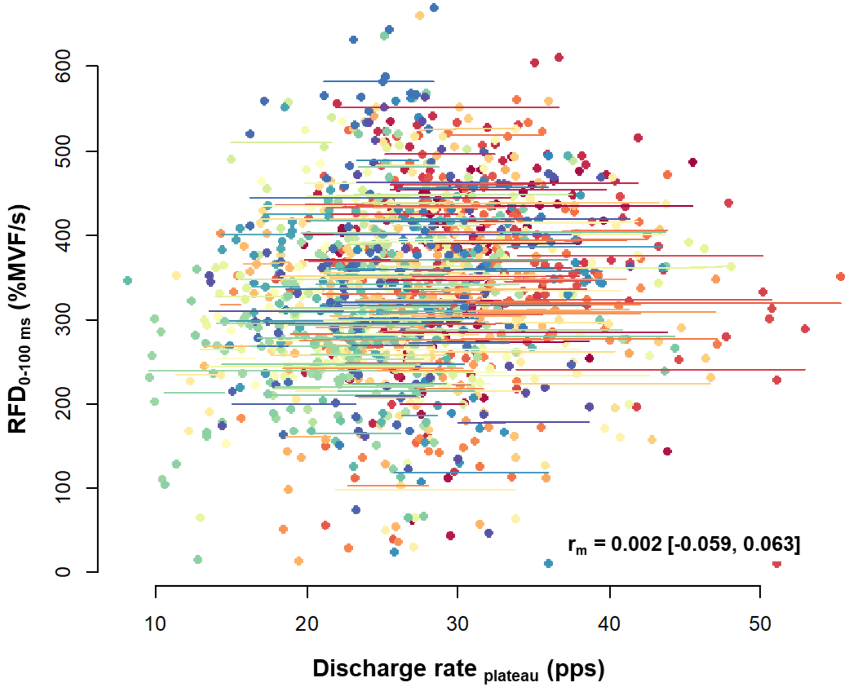
Dideriksen, Del Vecchio & Škarabot, *in prep*

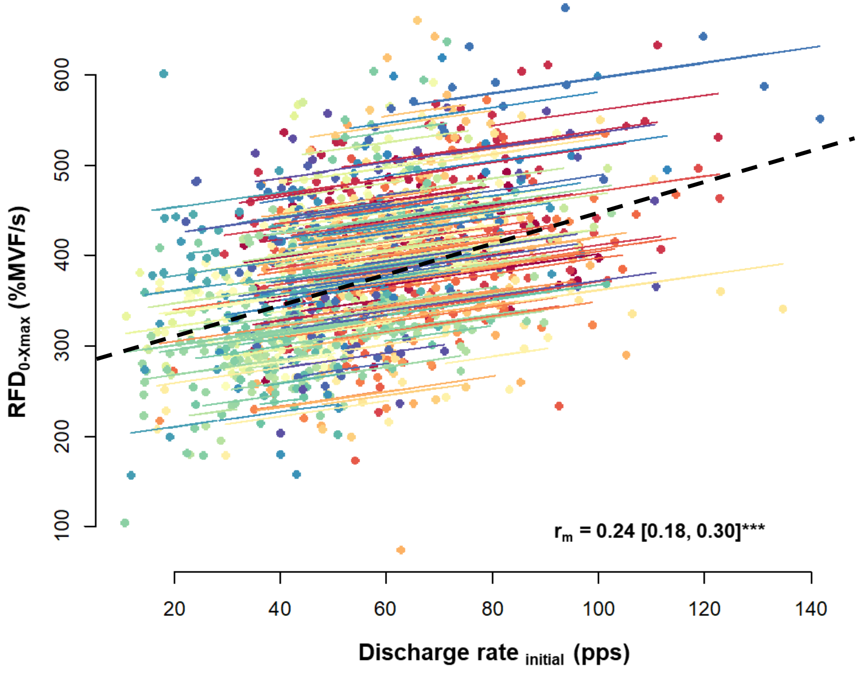
MU firing rate during rapid contractions



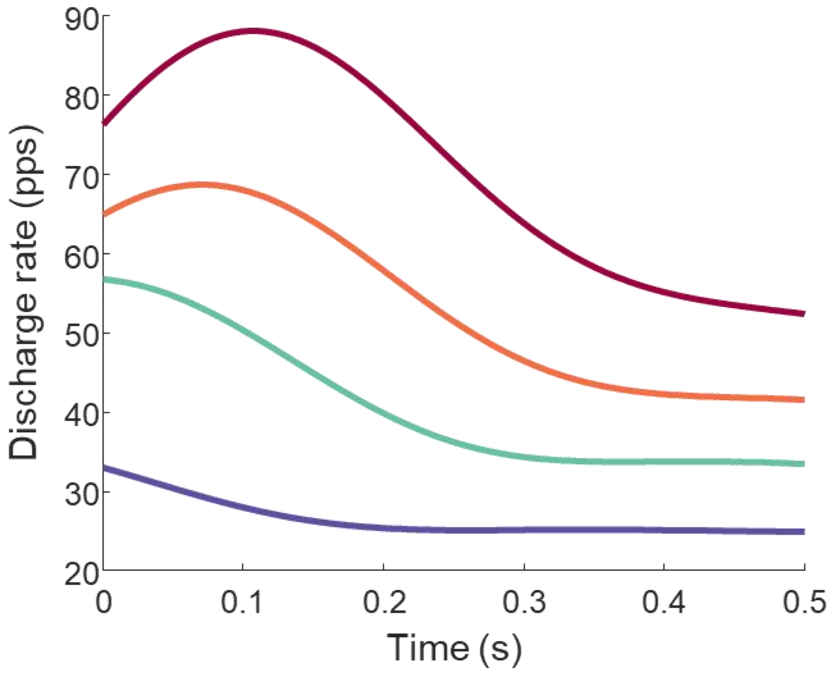
$$Discharge\ rate(j) = \frac{N}{\sum_{k=1}^{N}(s_{k+1}(j) - s_k(j))}$$

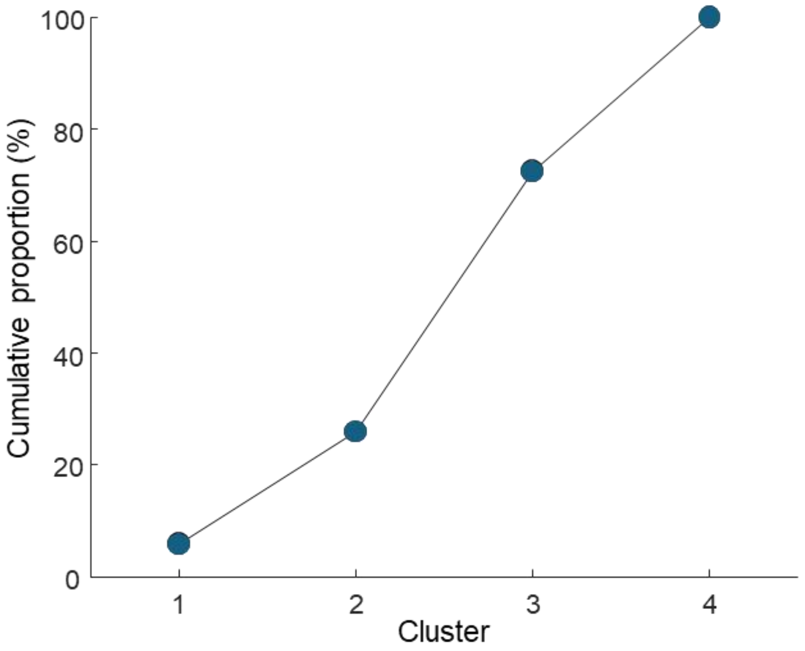


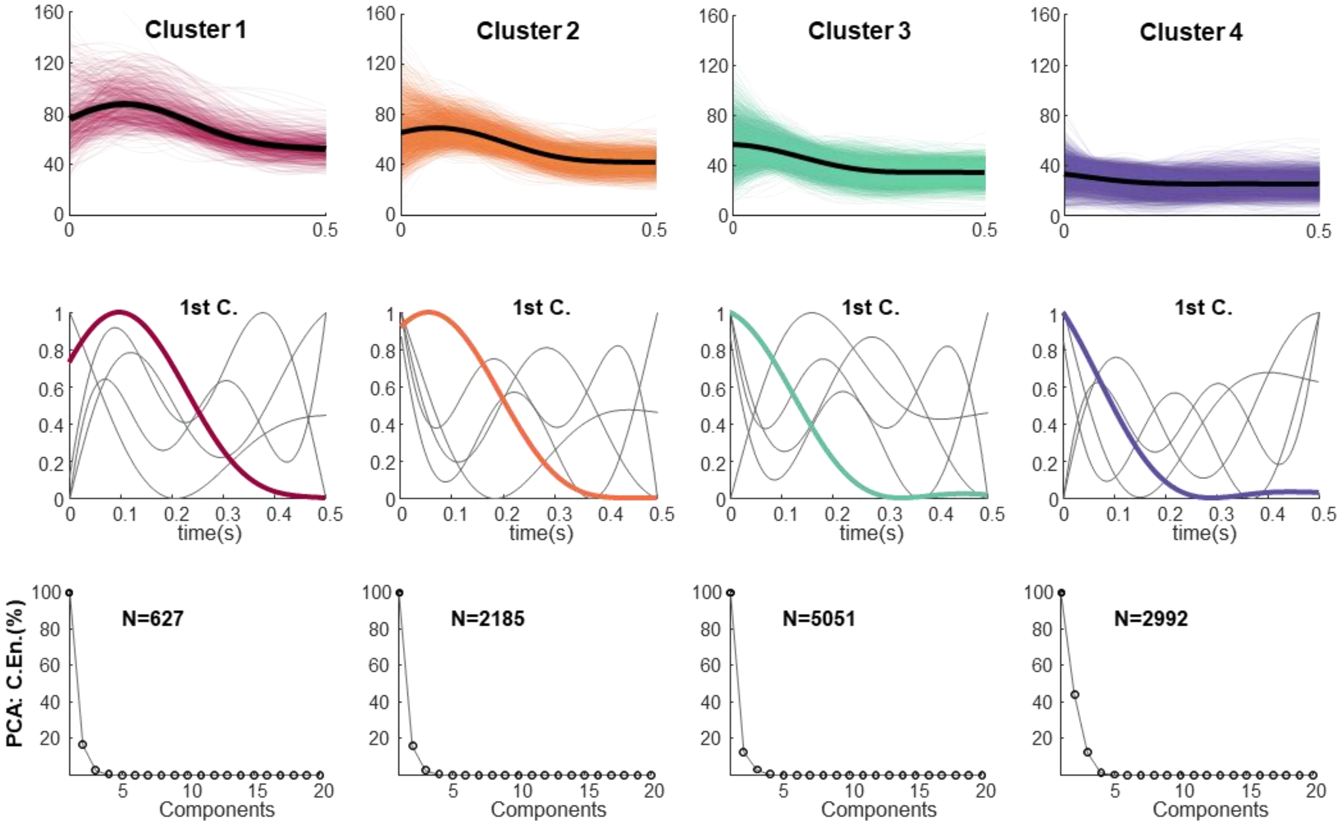




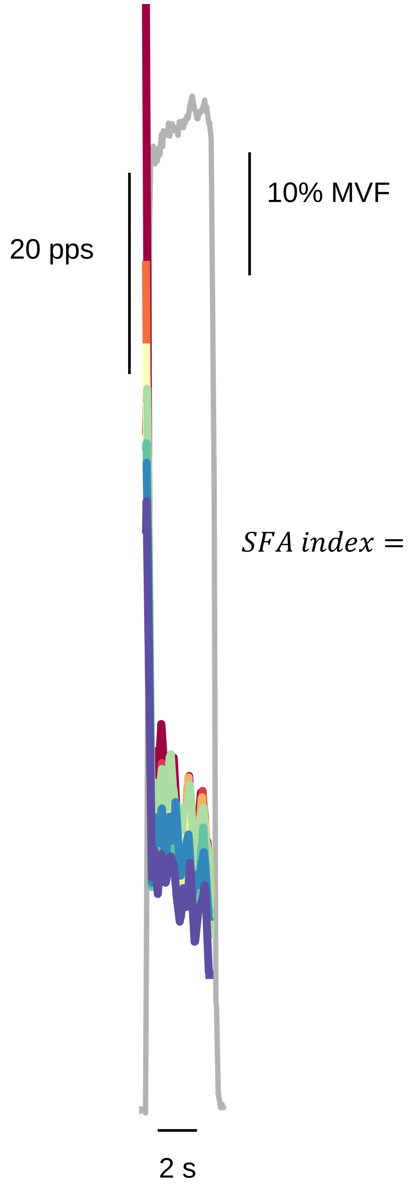
Clusters of MU firing patterns



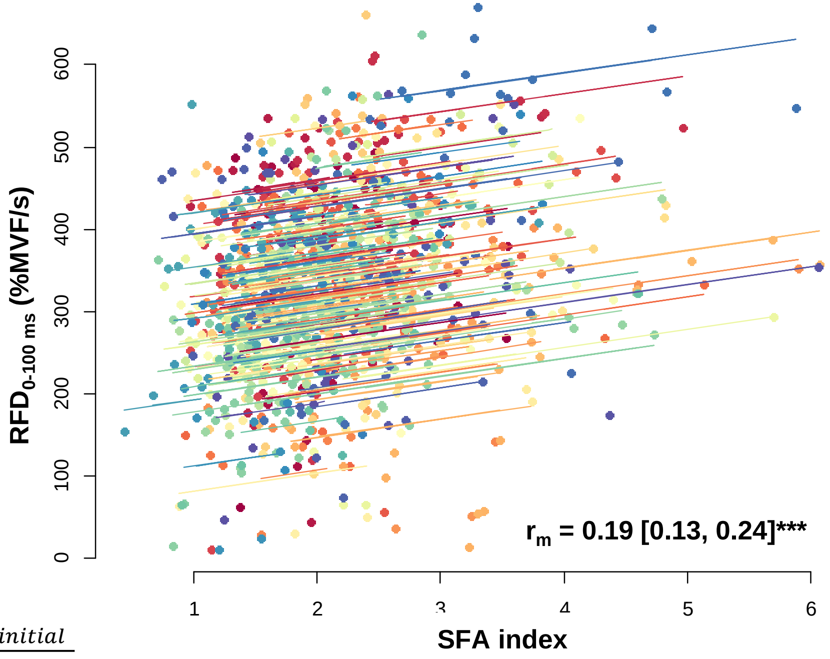


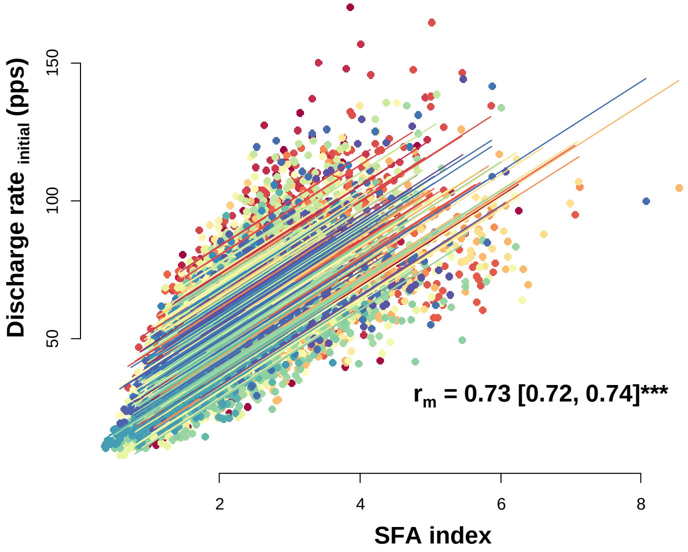


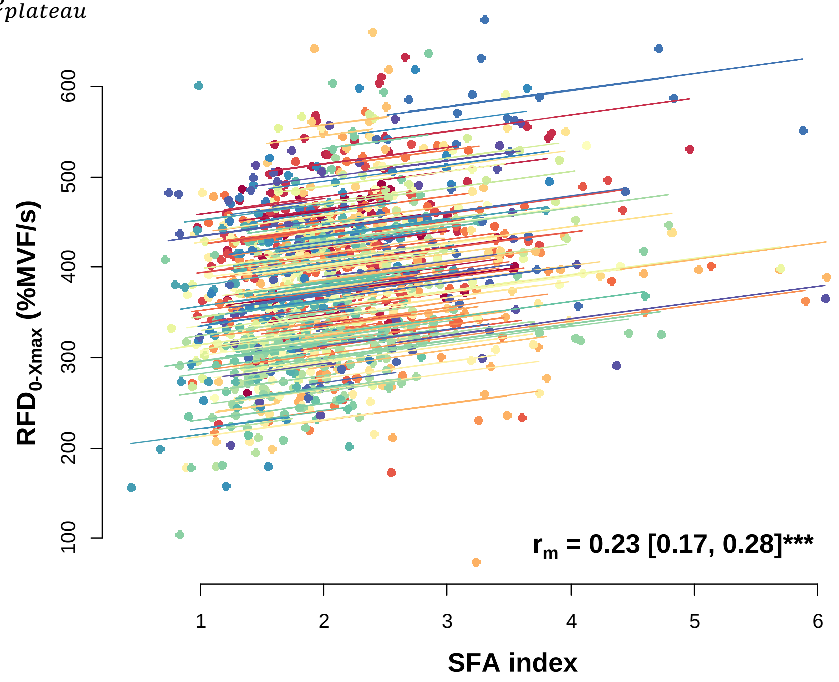
Spike frequency adaptation

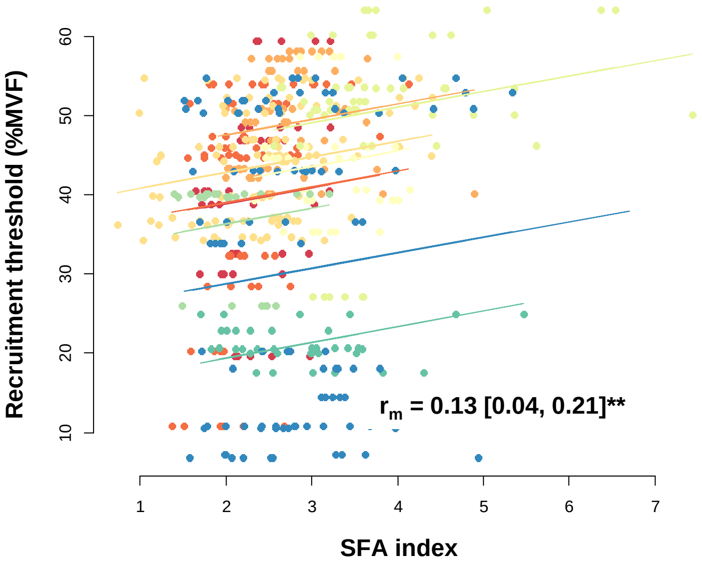


$$SFA\ index = \frac{Discharge\ rate_{initial}}{Discharge\ rate_{plateau}}$$

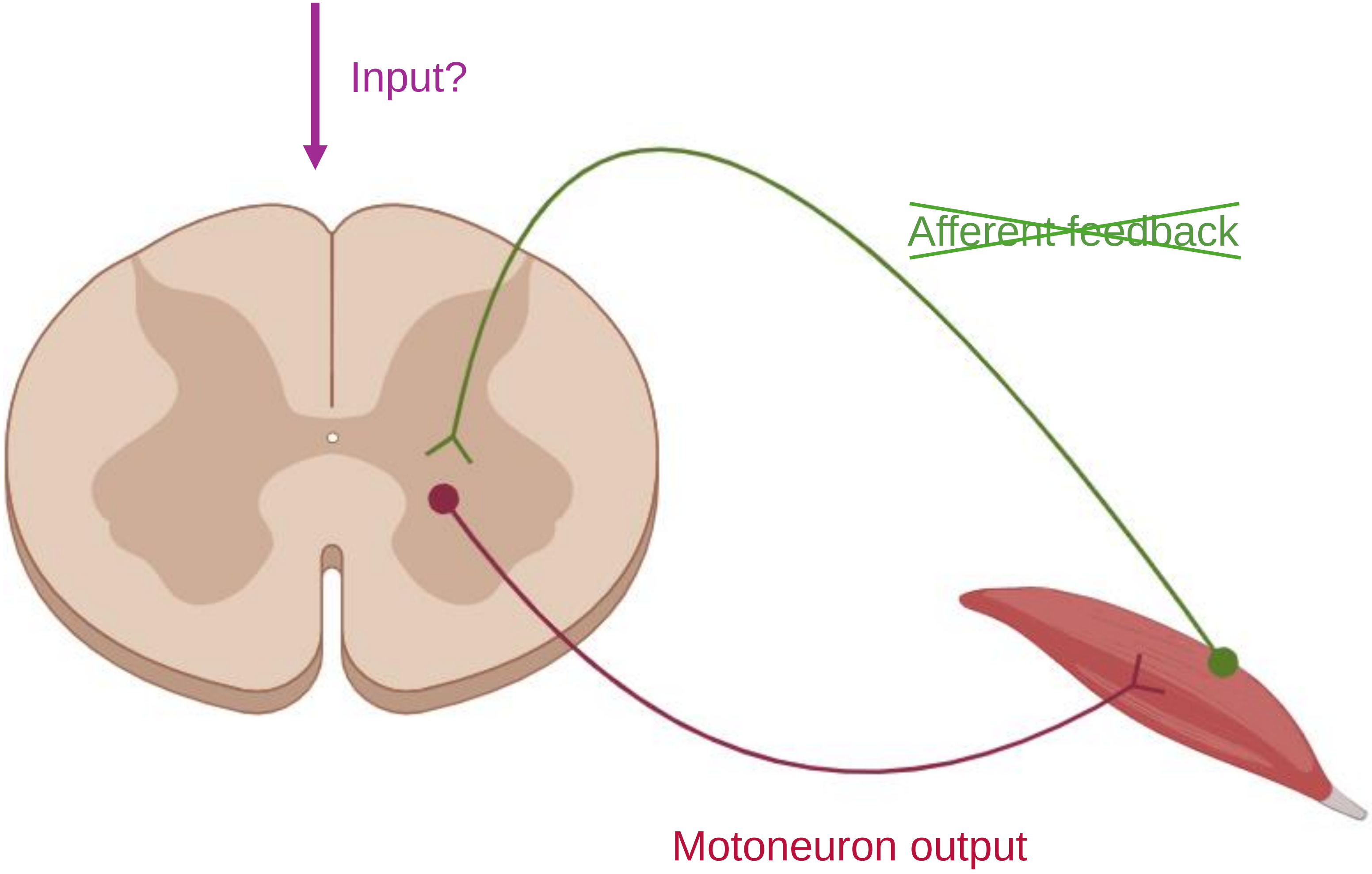


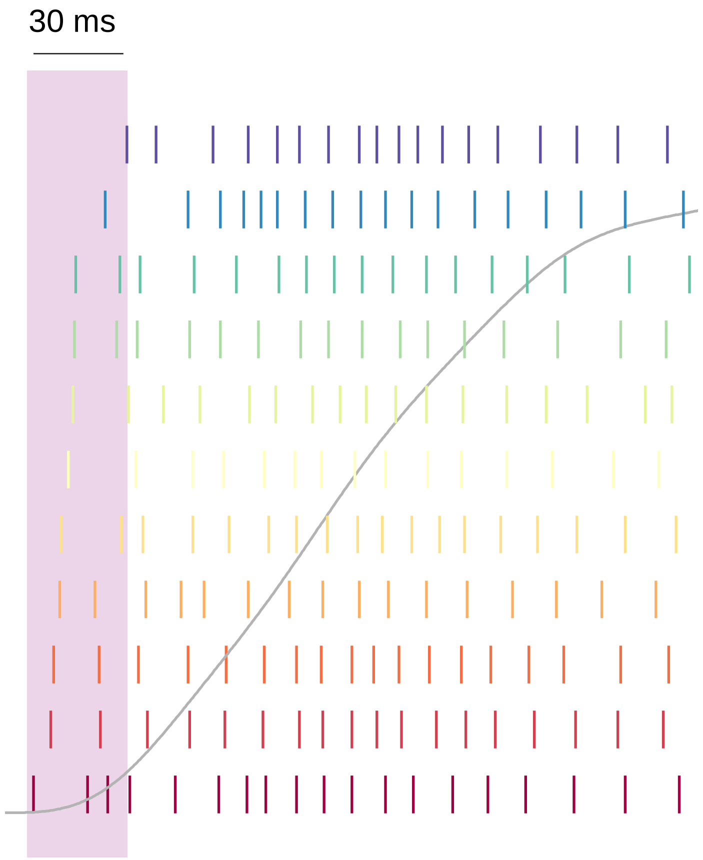




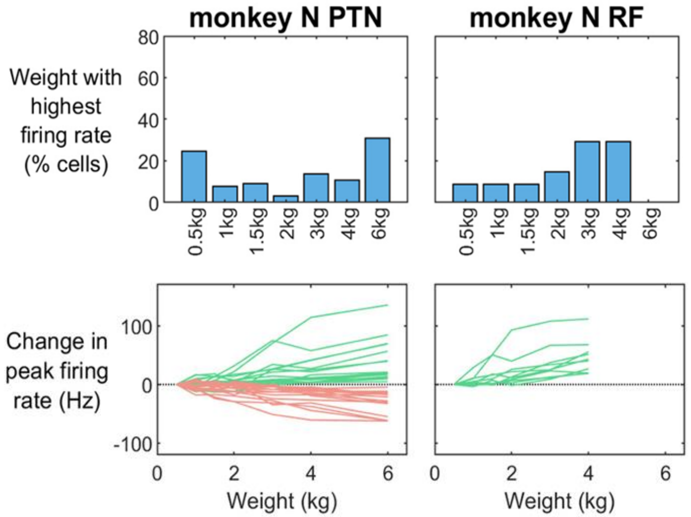


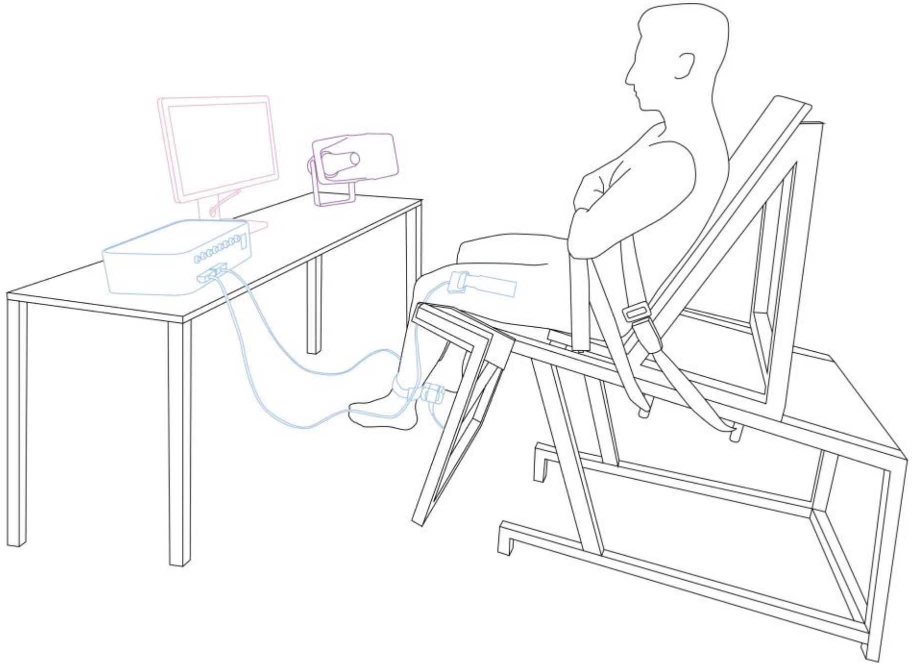
The neural substrate of motor unit behaviour during rapid contractions

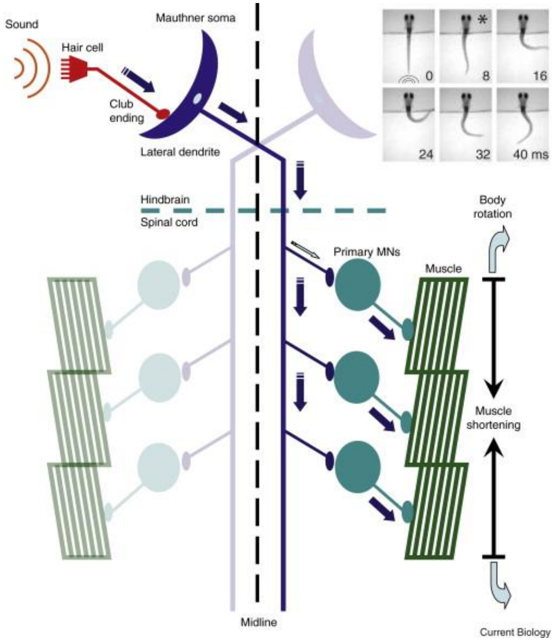


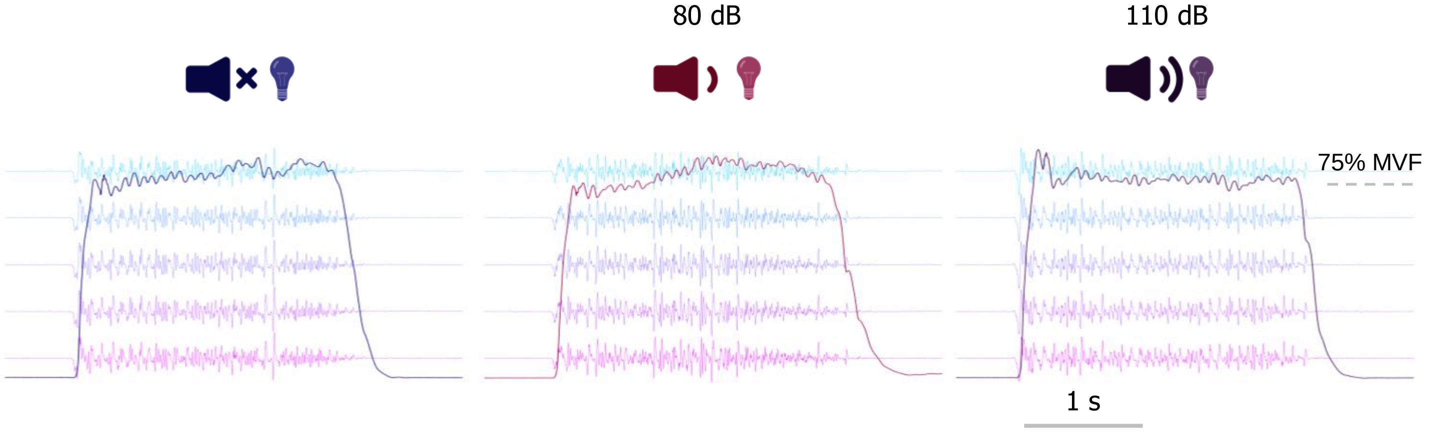


The neural substrate of motor unit behaviour during rapid contractions

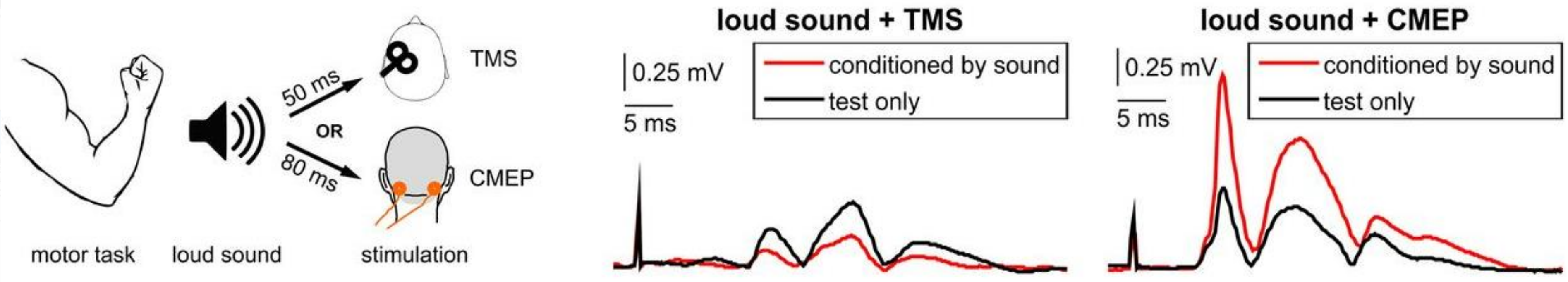




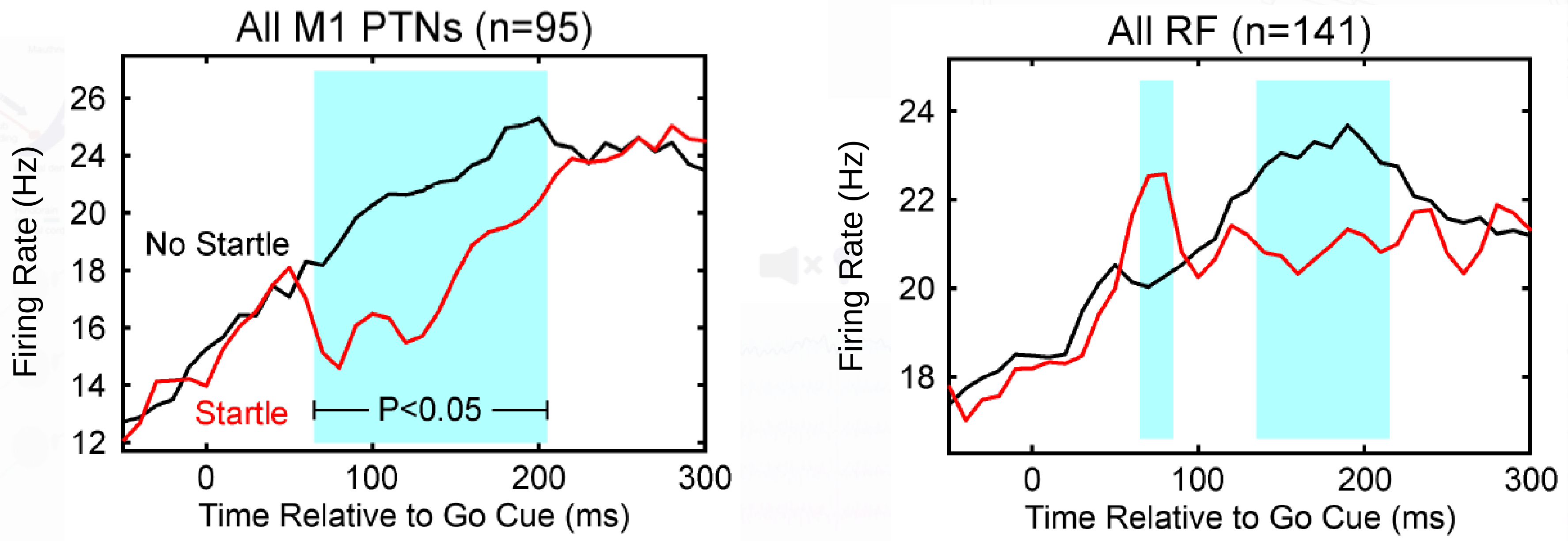




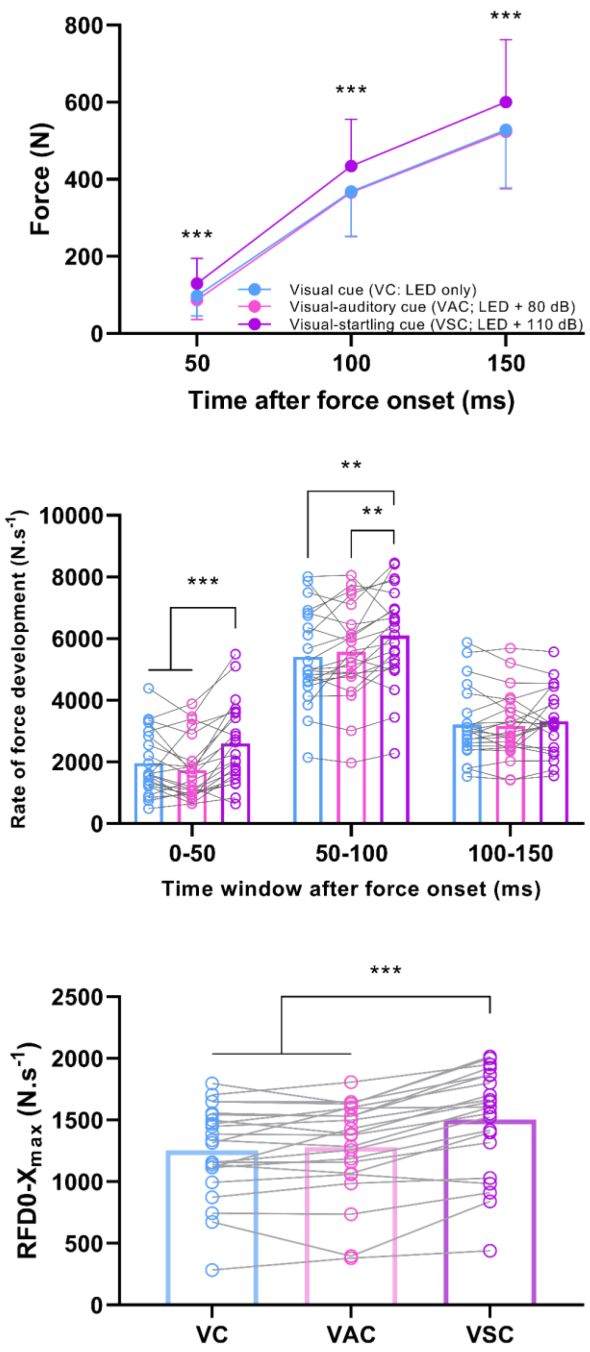
Škarabot et al. 2022, *J Neurophysiol*



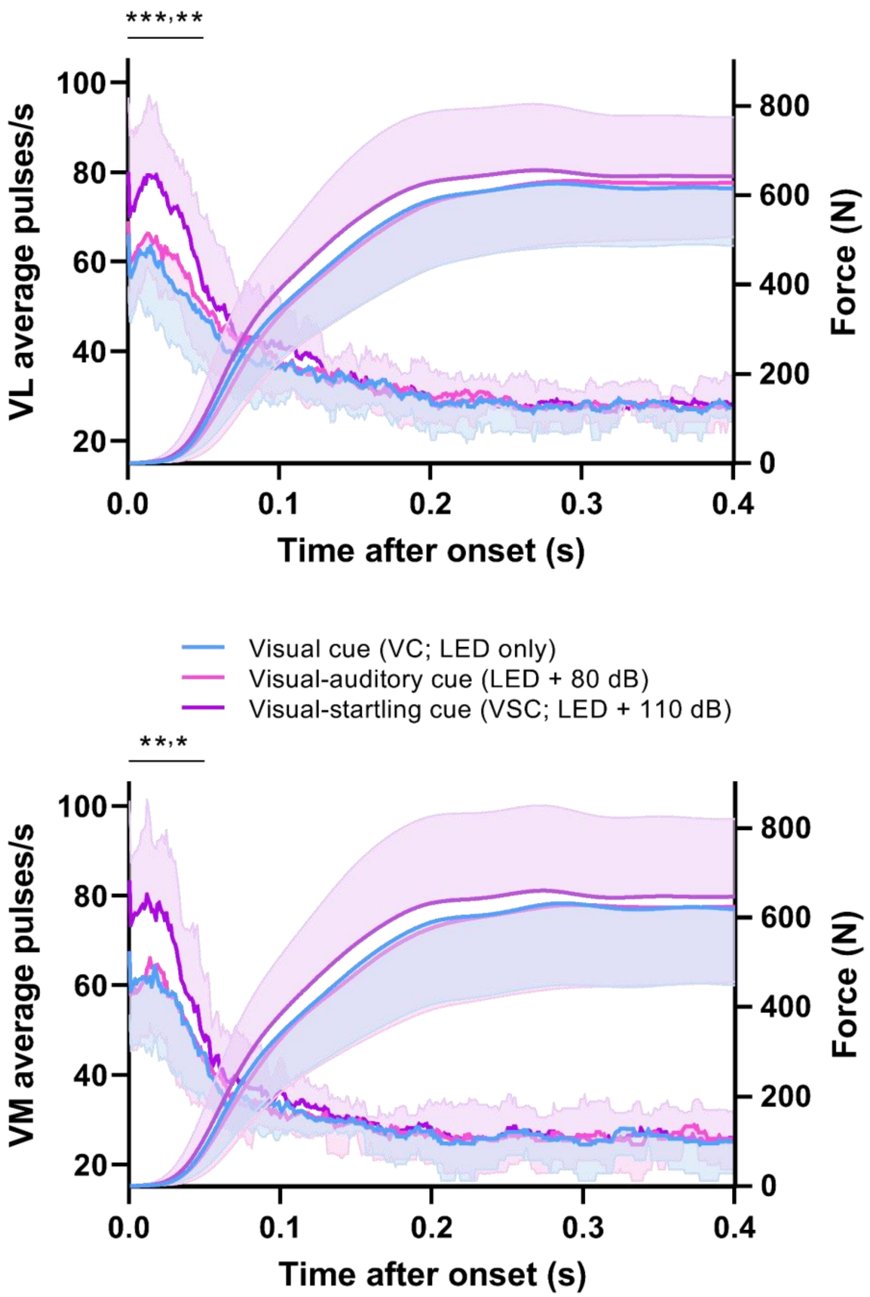
Germann & Baker 2021, *J Neurosci*



Tapia et al. 2022, *J Neurosci*



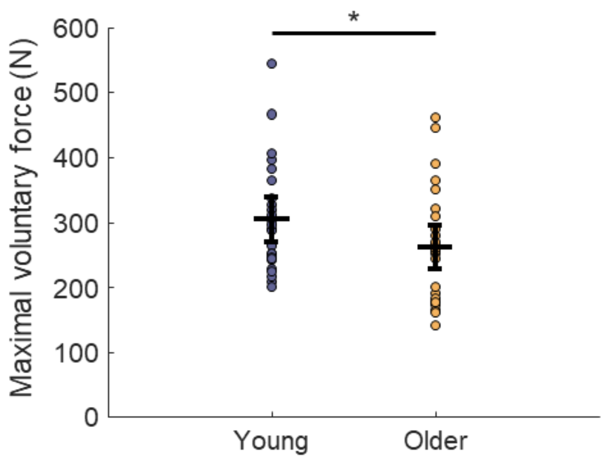
***p<0.001
**p<0.010
*p<0.05

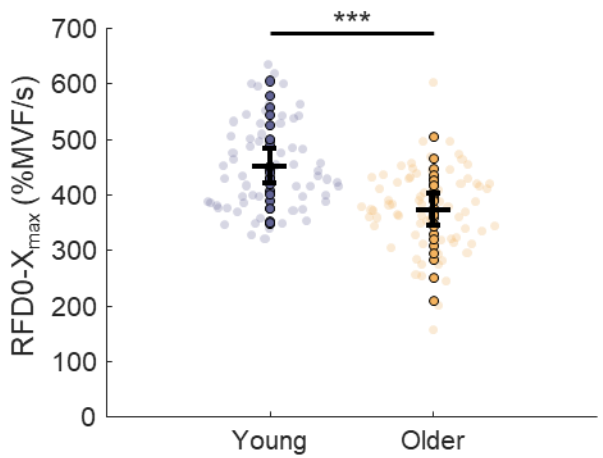


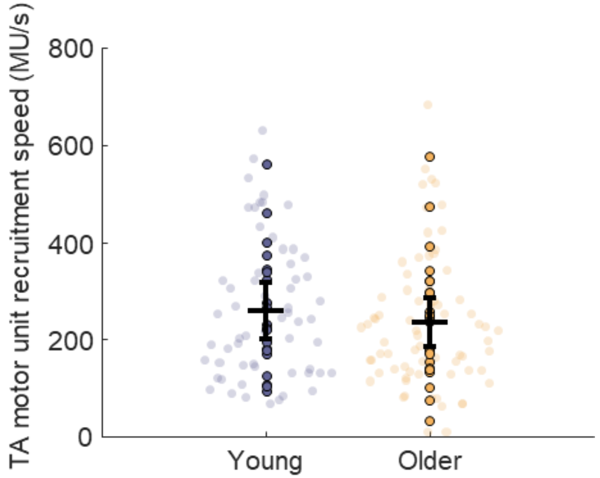
Škarabot et al. 2022, *J Neurophysiol*

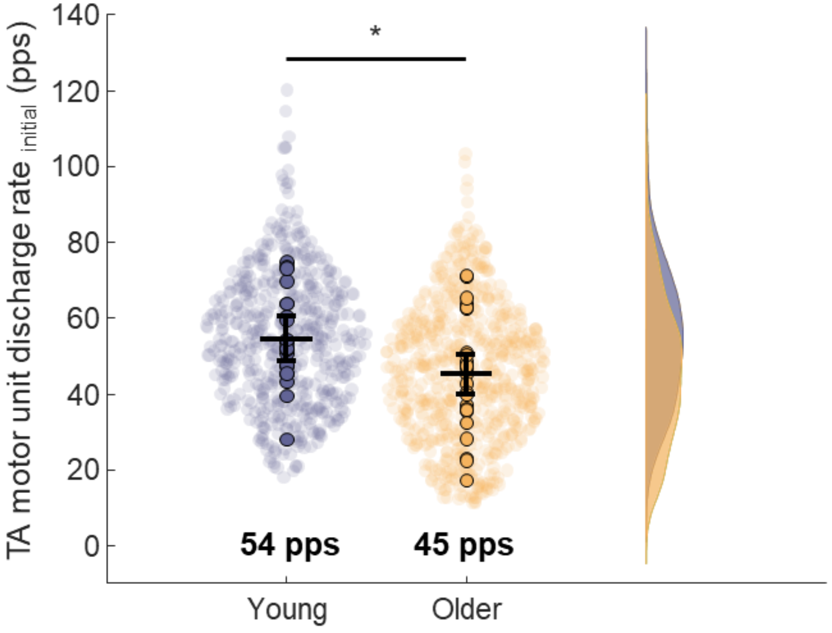
Rapid force production and MU firing in older vs. young individuals

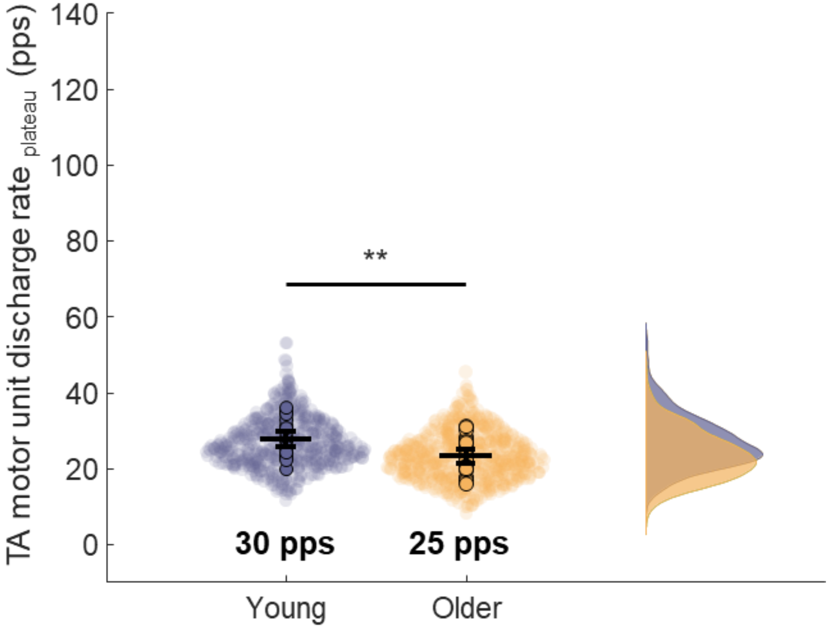
Young	Older
n = 26	n = 26
= 13	n = 13
= 13	n = 13
24 (± 4) years	73 (± 4) years
3938 (± 2320) MET.min/wk	3431 (± 2603) MET.min/wk







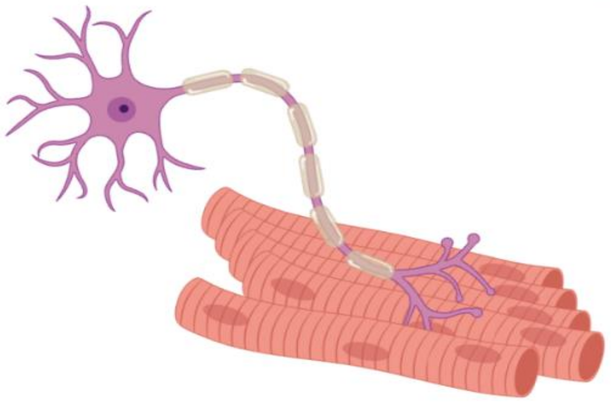


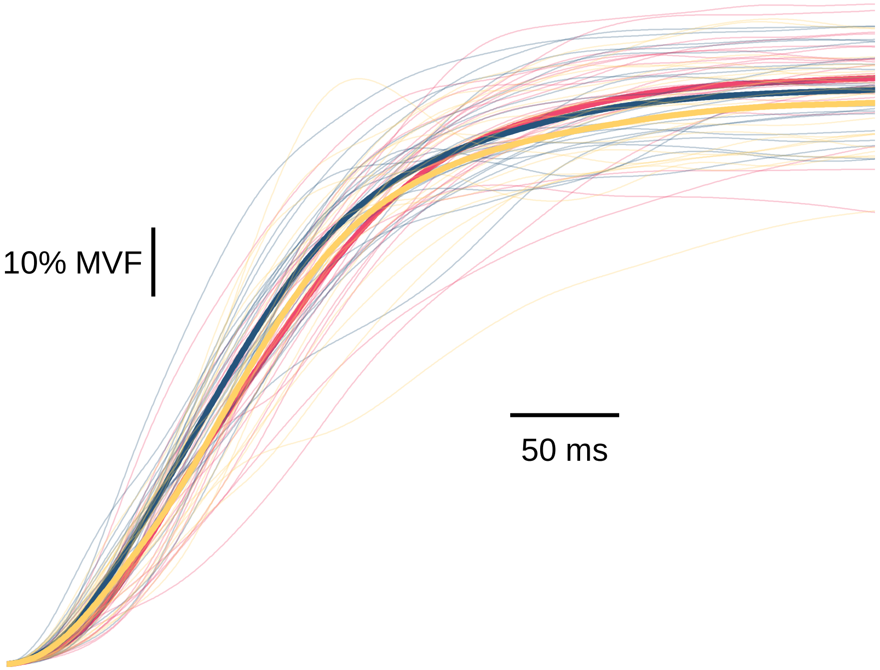


Chris Connelly

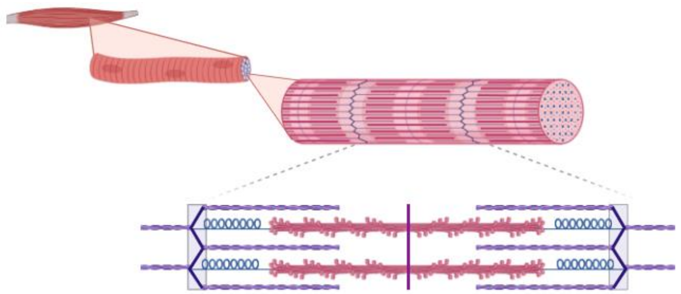
Rapid force production and MU firing in chronically trained individuals

NEURAL



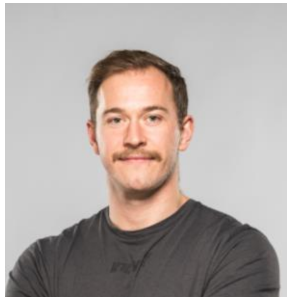


CONTRACTILE APPARATUS



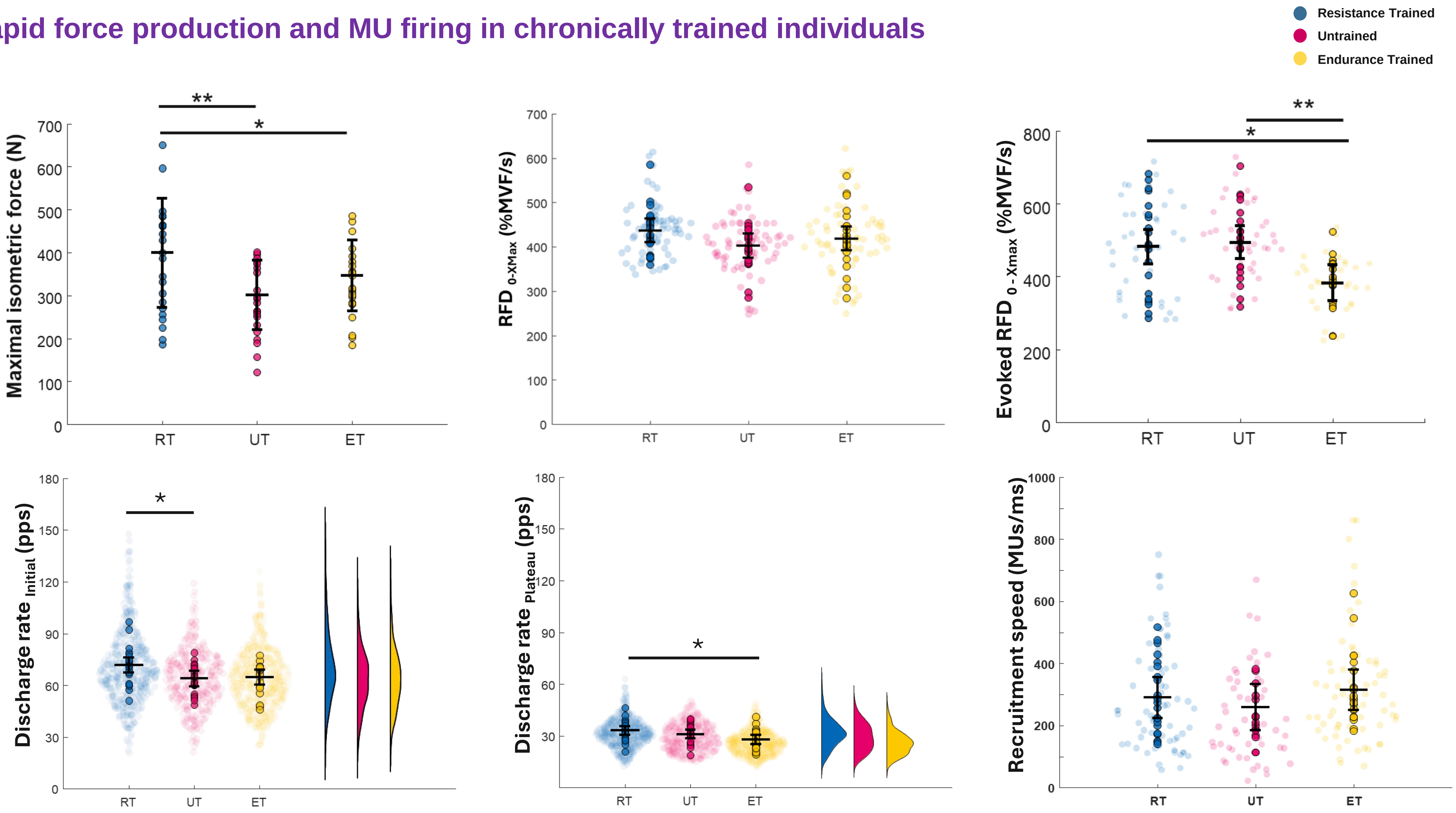
	Resistance Trained	Untrained	Endurance Trained
Neural Drive	↑	↔	↔
Contractile Properties	↑ ↔	↔	↓

	RT (n=22)	UT (n=22)	ET (n=22)
Training Age (yrs)	9 ± 3	-	10 ± 4
IPAQ (MET-min/week)	**6401± 2729***	4038 ± 2380	**6590 ± 2128****
Mass (kg)	**84 ± 17****	70 ± 12	68 ± 8
Height (m)	1.75 ± 0.08	1.73 ± 0.08	1.78 ± 0.08
Age (yrs)	23 ± 4	23 ± 3	24 ± 6



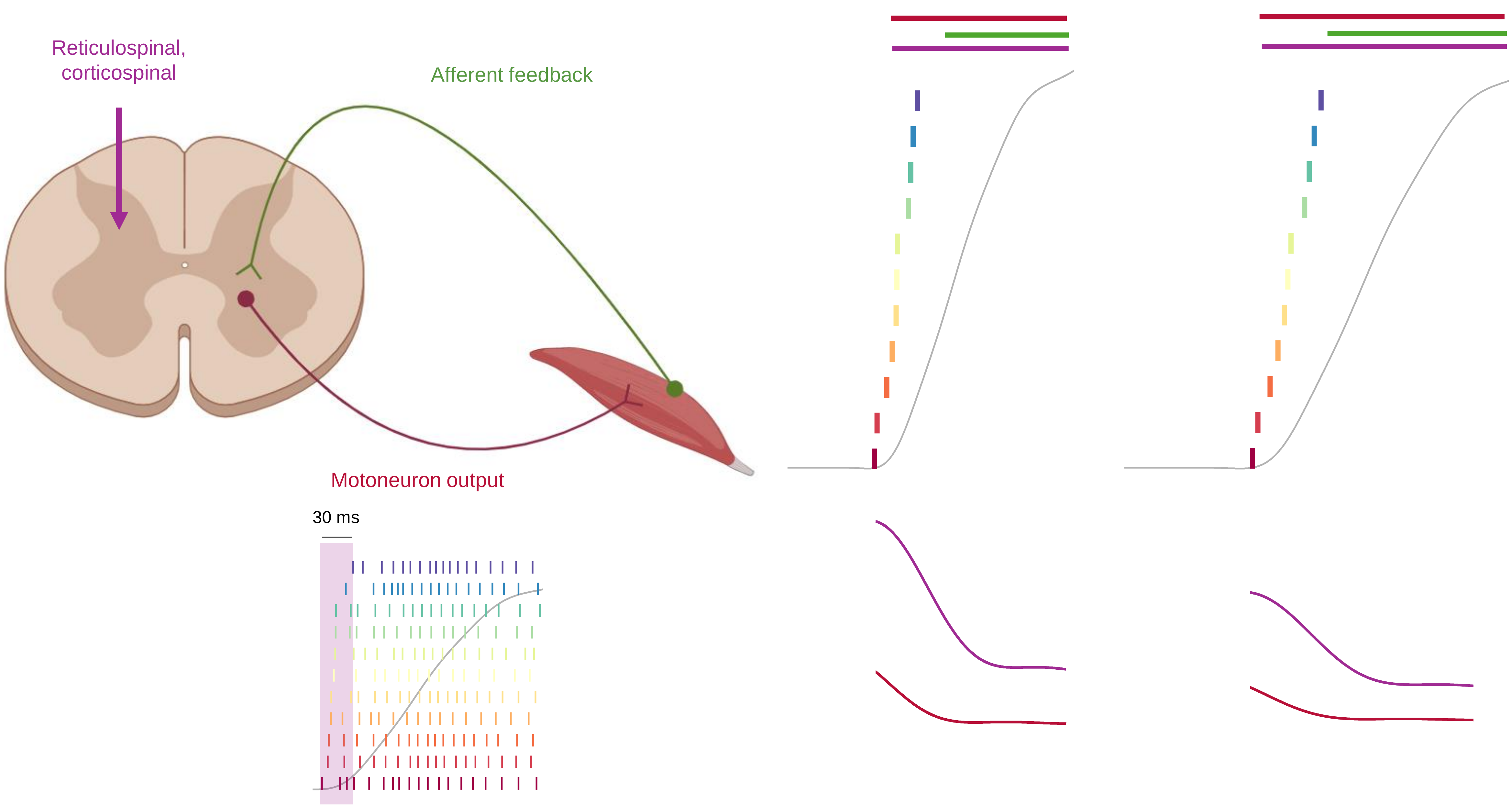
Haydn Thomason

Rapid force production and MU firing in chronically trained individuals

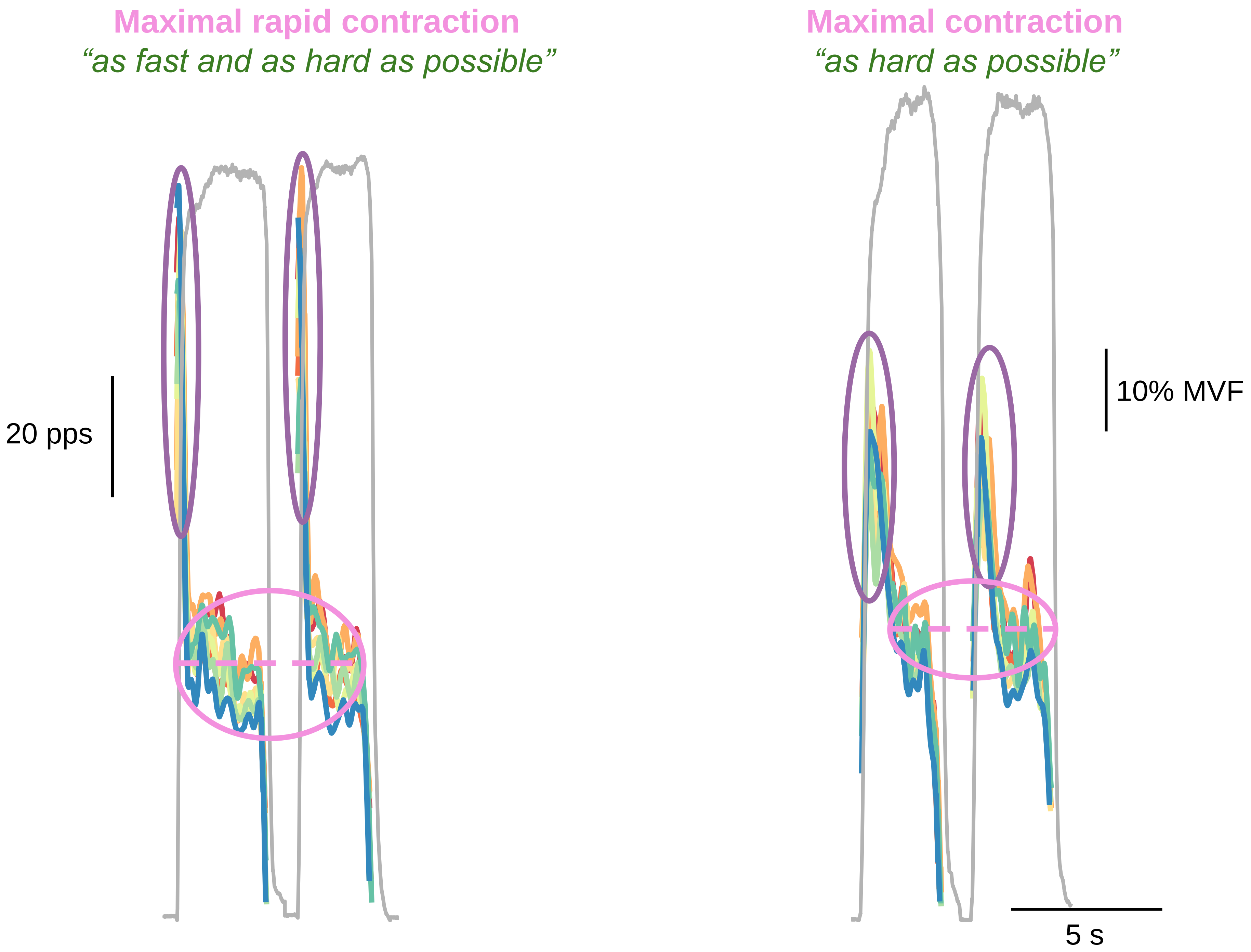


***, $p < 0.0001$; **, $p < 0.01$; *, $p < 0.05$

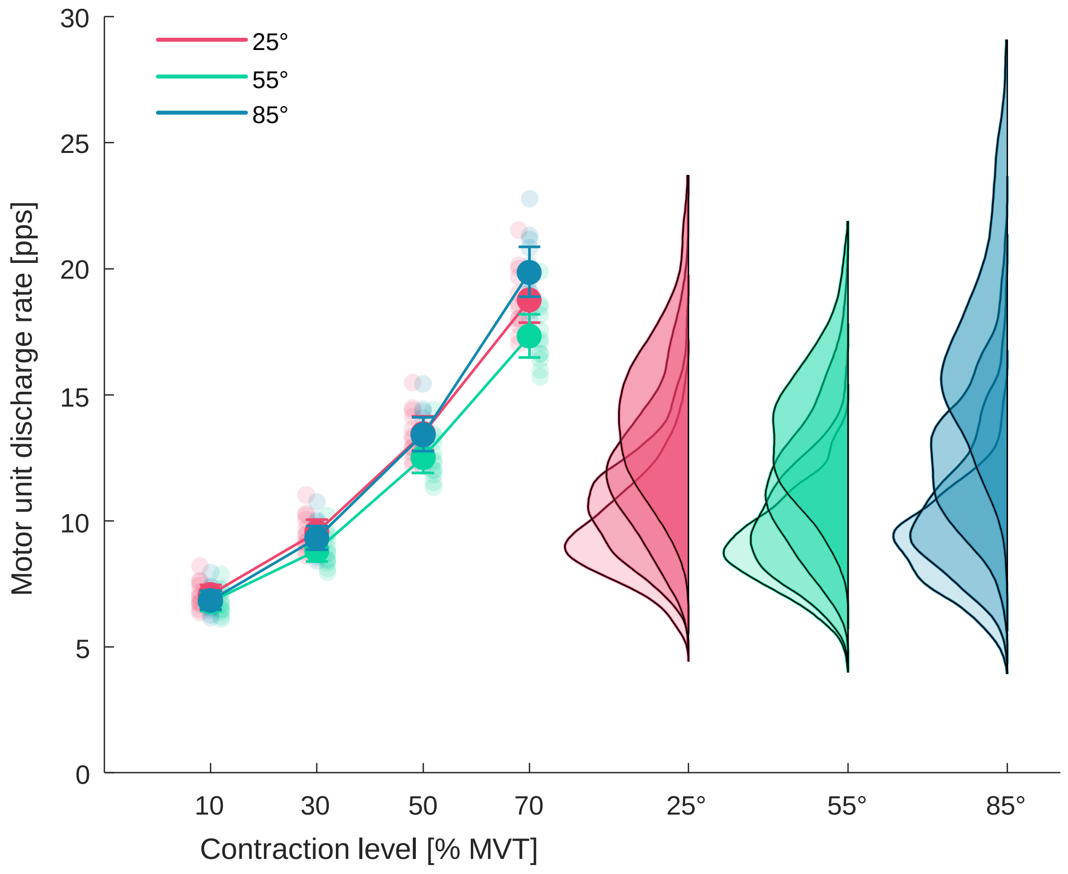
Rapid contractions → maximal human in vivo motoneuron output

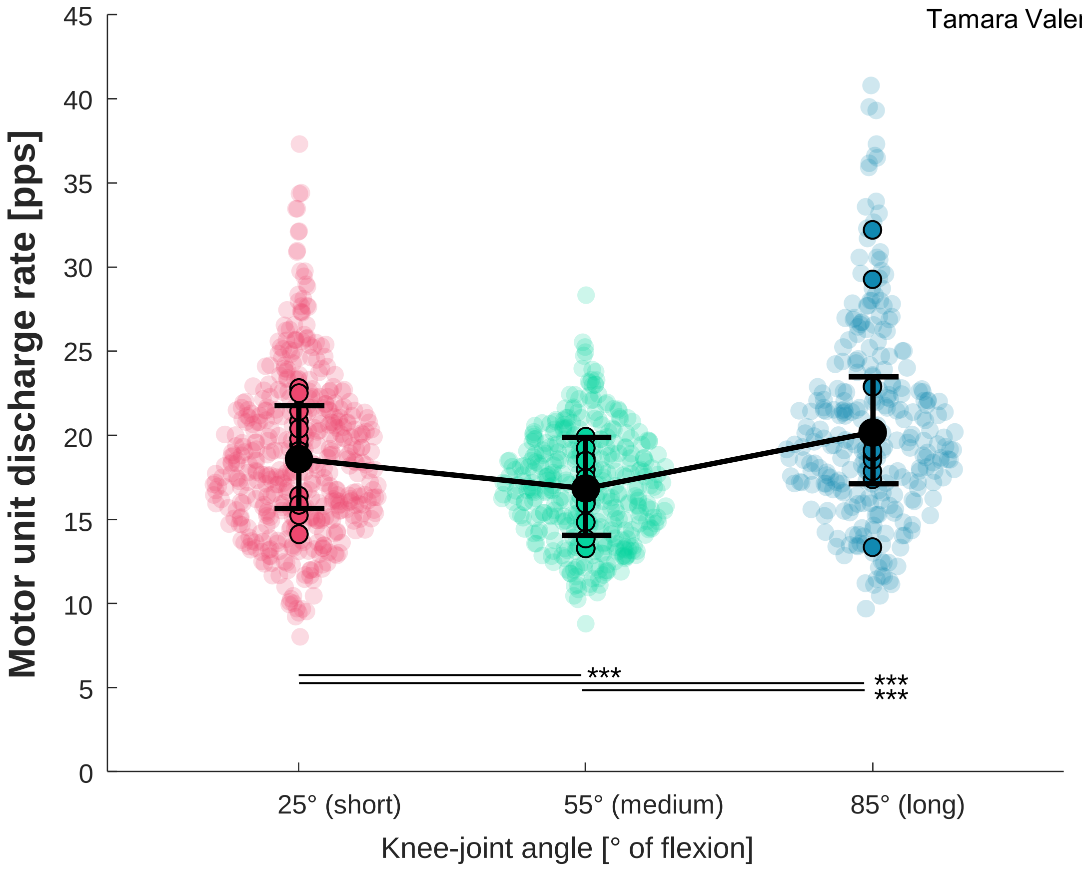


Rapid contractions → maximal human *in vivo* motoneuron output


Maximal rapid contraction
"as fast and as hard as possible"
Maximal contraction
"as hard as possible"
20 pps
10% MVF
5 s

Motor unit behaviour during maximal efforts





Tamara Valenčič

Valenčič et al., *in preparation*

Thank you

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