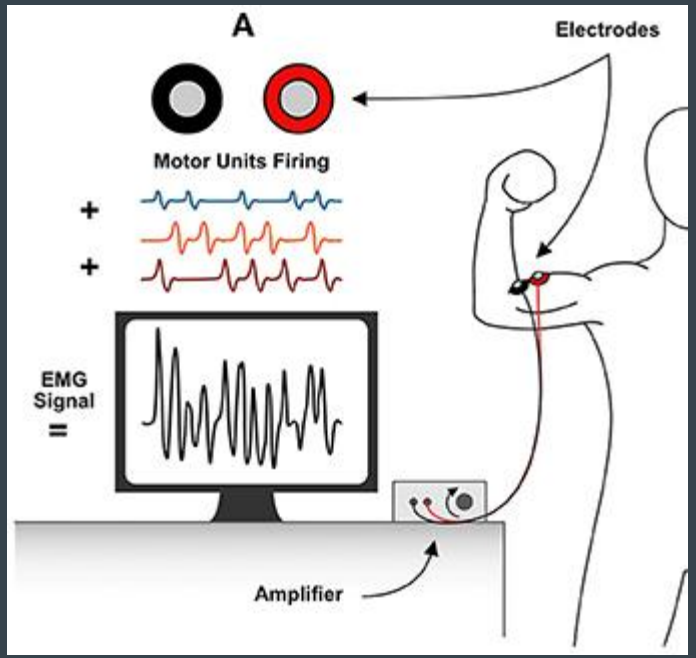
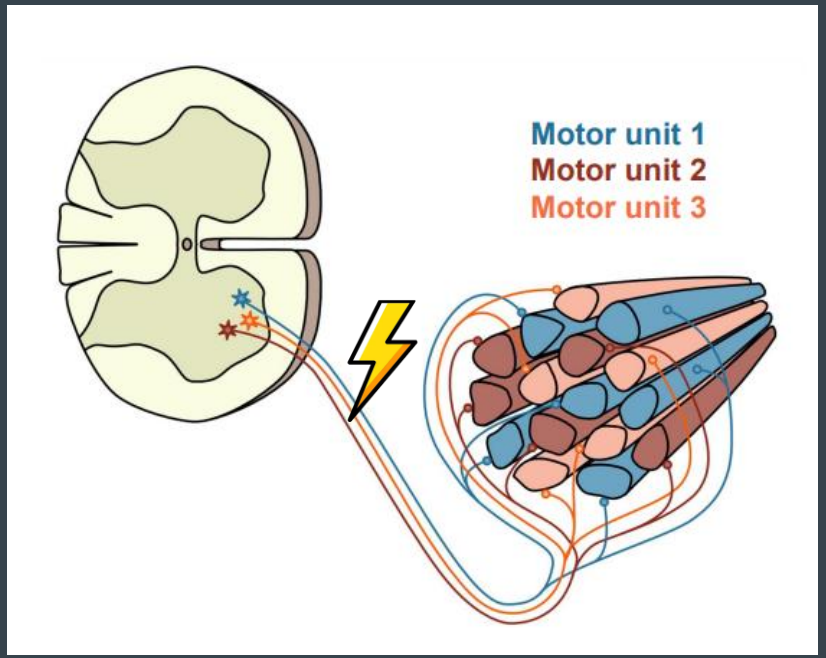
Can we (quickly) estimate soleus motor unit number and size from a CMAP scan with MScanFit?

Ricardo Mesquita
Postdoctoral Researcher
Division of Clinical Physiology, Karolinska Institutet

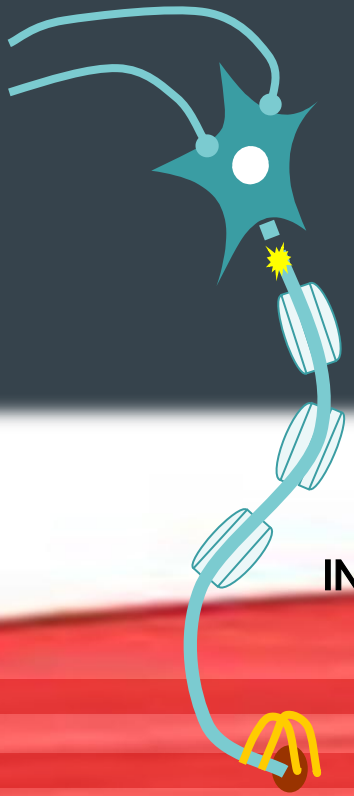
Nationella Utbildnings i neurofysiologi
02/02/2026





(Hamstreet & Muceli, 2022)

ricardo.mesquita@ki.se



INNERVATION ZONES

MUSCLE FIBERS

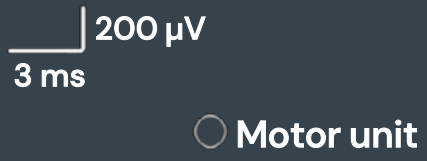
Evoked response

Motor unit

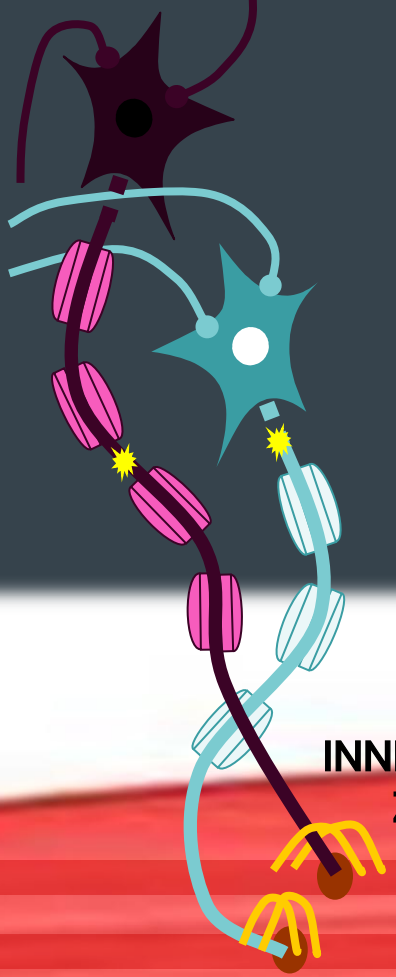
Adapted from de Carvalho et al. (2018)

Motor unit action potentials

Evoked response

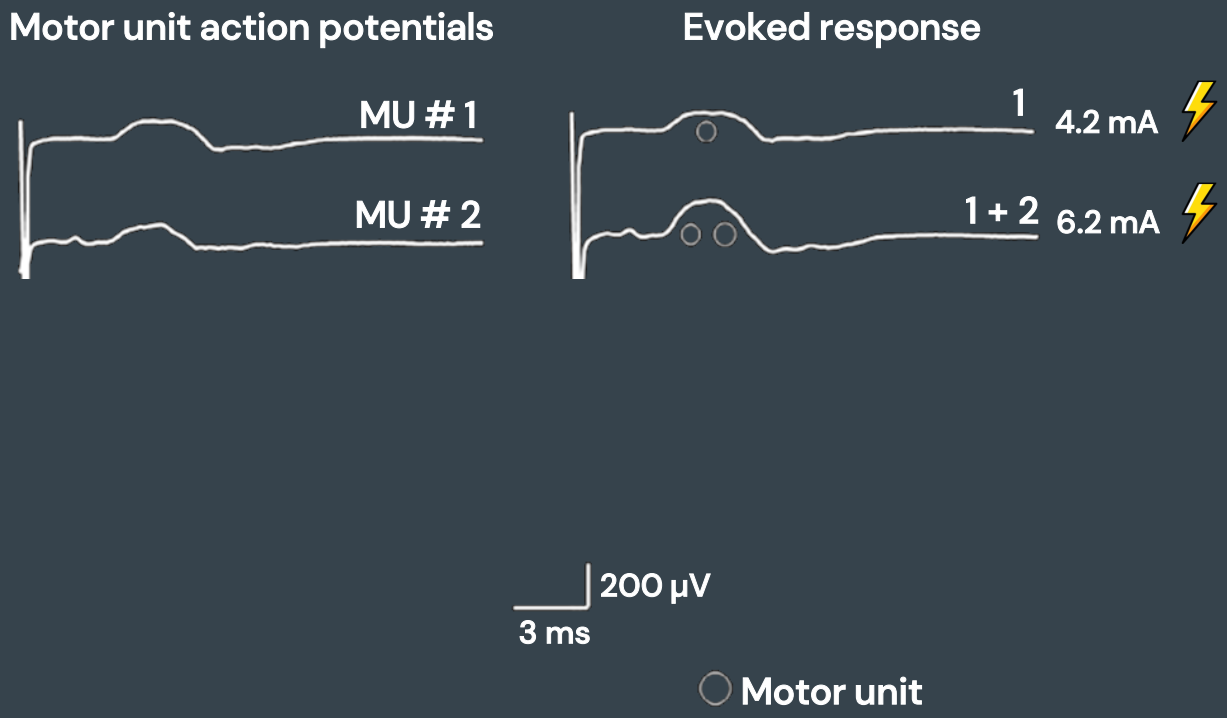


Adapted from de Carvalho et al. (2018)

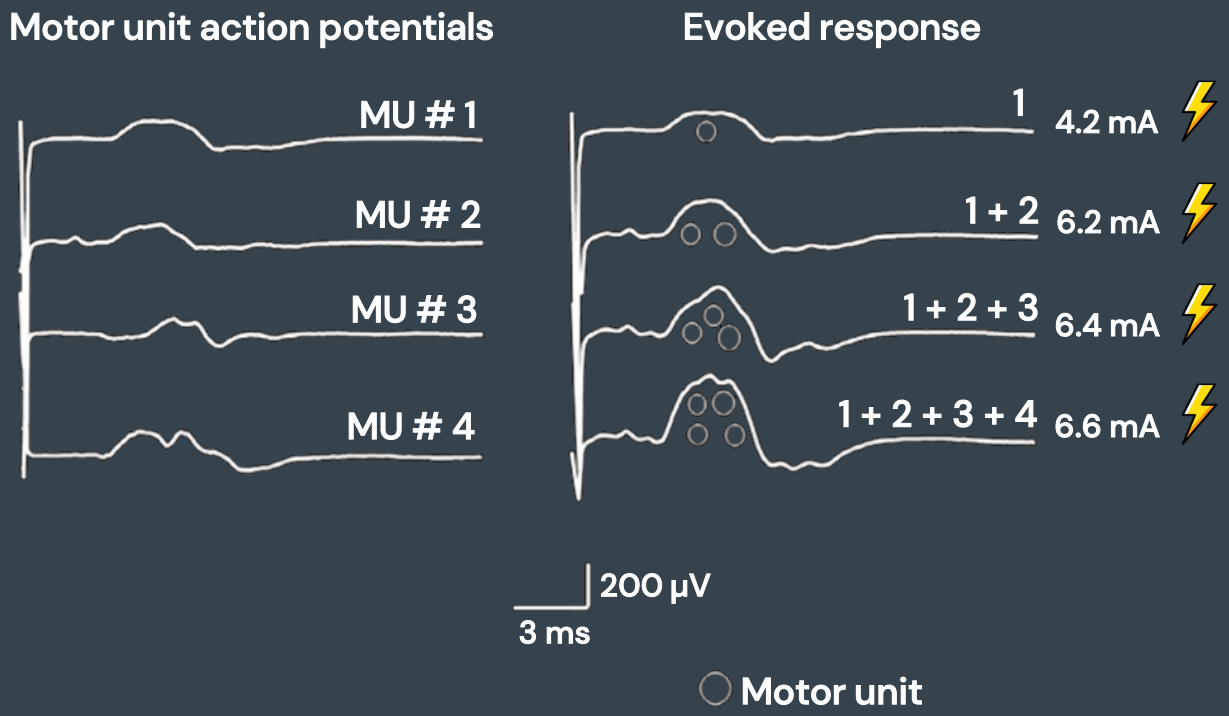


INNERVATION ZONES

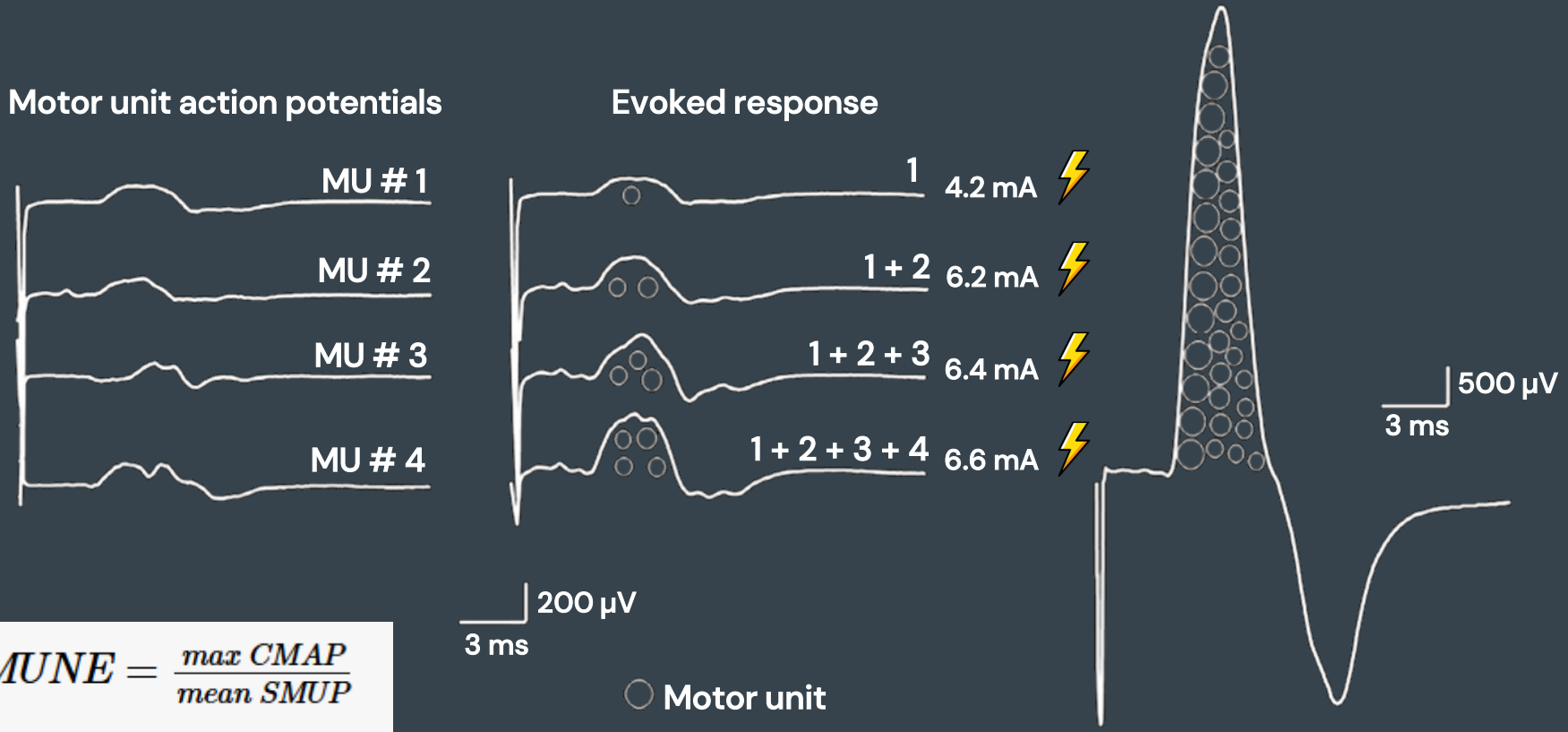
MUSCLE FIBERS



Adapted from de Carvalho et al. (2018)



Adapted from de Carvalho et al. (2018)



$$MUNE = \frac{max\ CMAP}{mean\ SMUP}$$

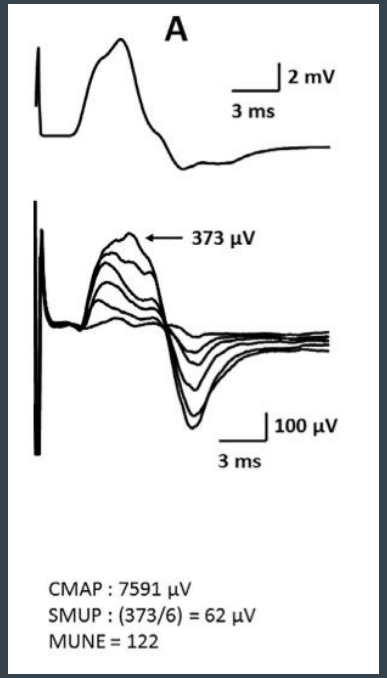
Adapted from de Carvalho et al. (2018)

$$MUNE = \frac{max\ CMAP}{mean\ SMUP}$$

MUNE treats the CMAP as a “bag of motor units”

If we know how big the whole bag is and
how big one motor unit typically is,
we can estimate how many units must be inside.

Non-automated incremental techniques



de Carvalho et al. (2018)

- Around ~10 sMUPs are estimated to calculate an average sMUP

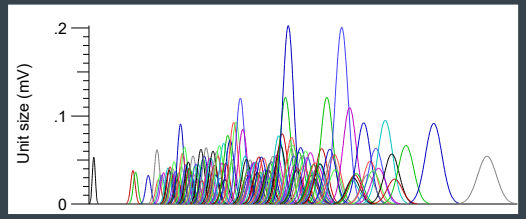
Some limitations:

- Sampling bias (are the 10 sMUPs representative?)
- Assumption that MUAPs sum linearly
- Alternation
- Phase cancellation
- Not automated (operator-dependent / subjectivity)
- Time-consuming

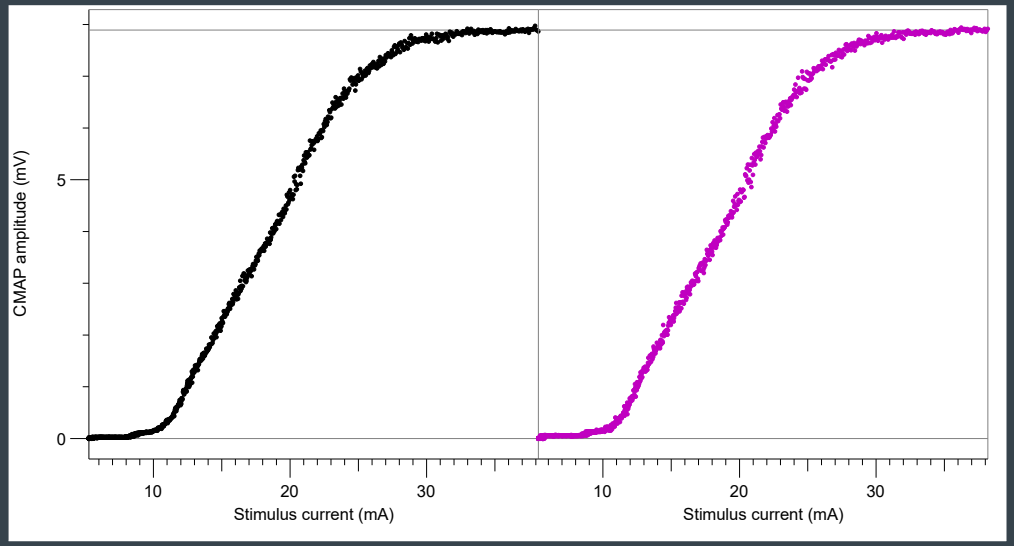
$$MUNE = \frac{max\ CMAP}{mean\ SMUP}$$

MScanFit (CMAP scan)

Number of units = 155
Fit error = 1.29
SD(foot) = 4.8uV, SD(top) = 22.1uV



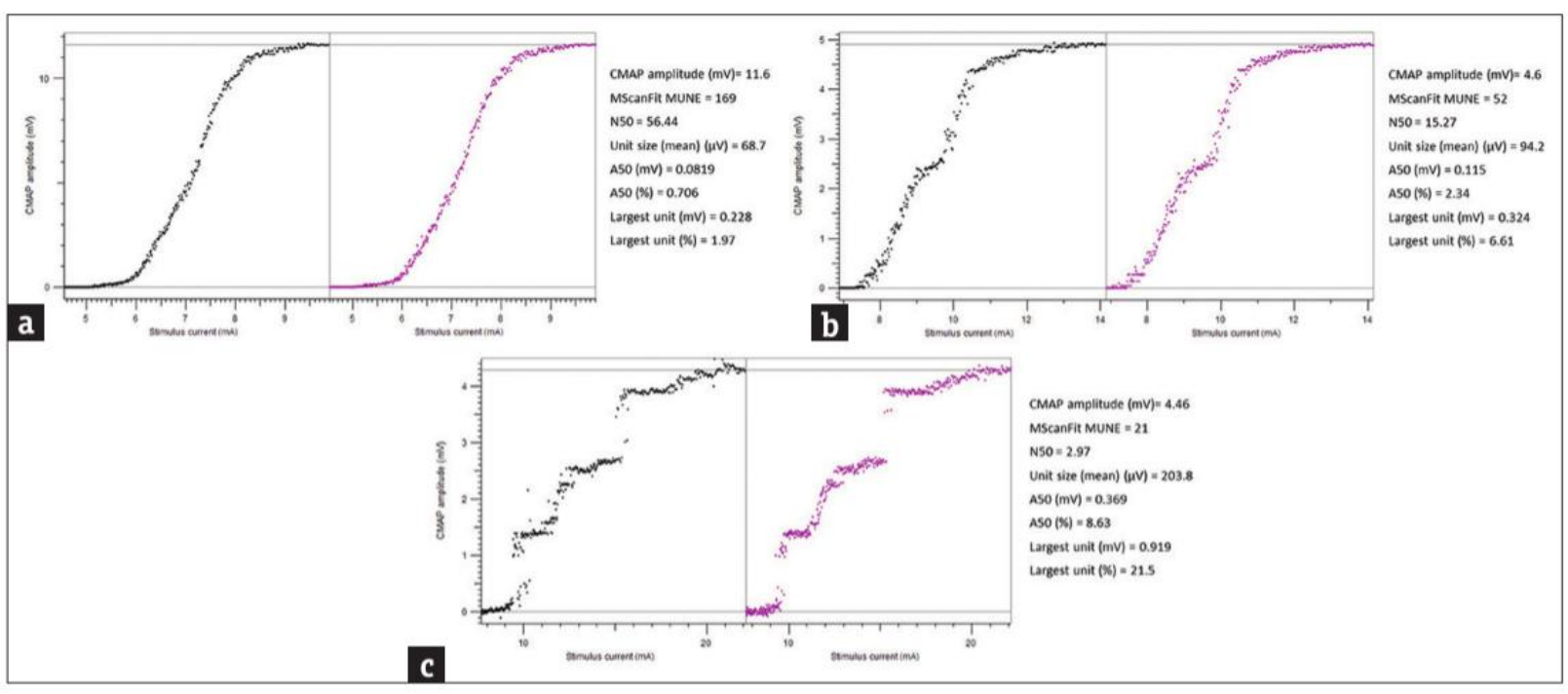
$$MUNE = \frac{max\ CMAP}{mean\ SMUP}$$



Overview of the whole motor unit pool

- Gradual stimulation from supramaximal to subthreshold
- Hundreds of stimulus steps
- MUNE + parameters related to motor unit size distribution, etc

MScanFit (CMAP scan)



Tankisi (2021)

MScanFit (CMAP scan)

1. More detailed and unbiased: full pattern of the EMG response to stimulation (Bostock, 2016)

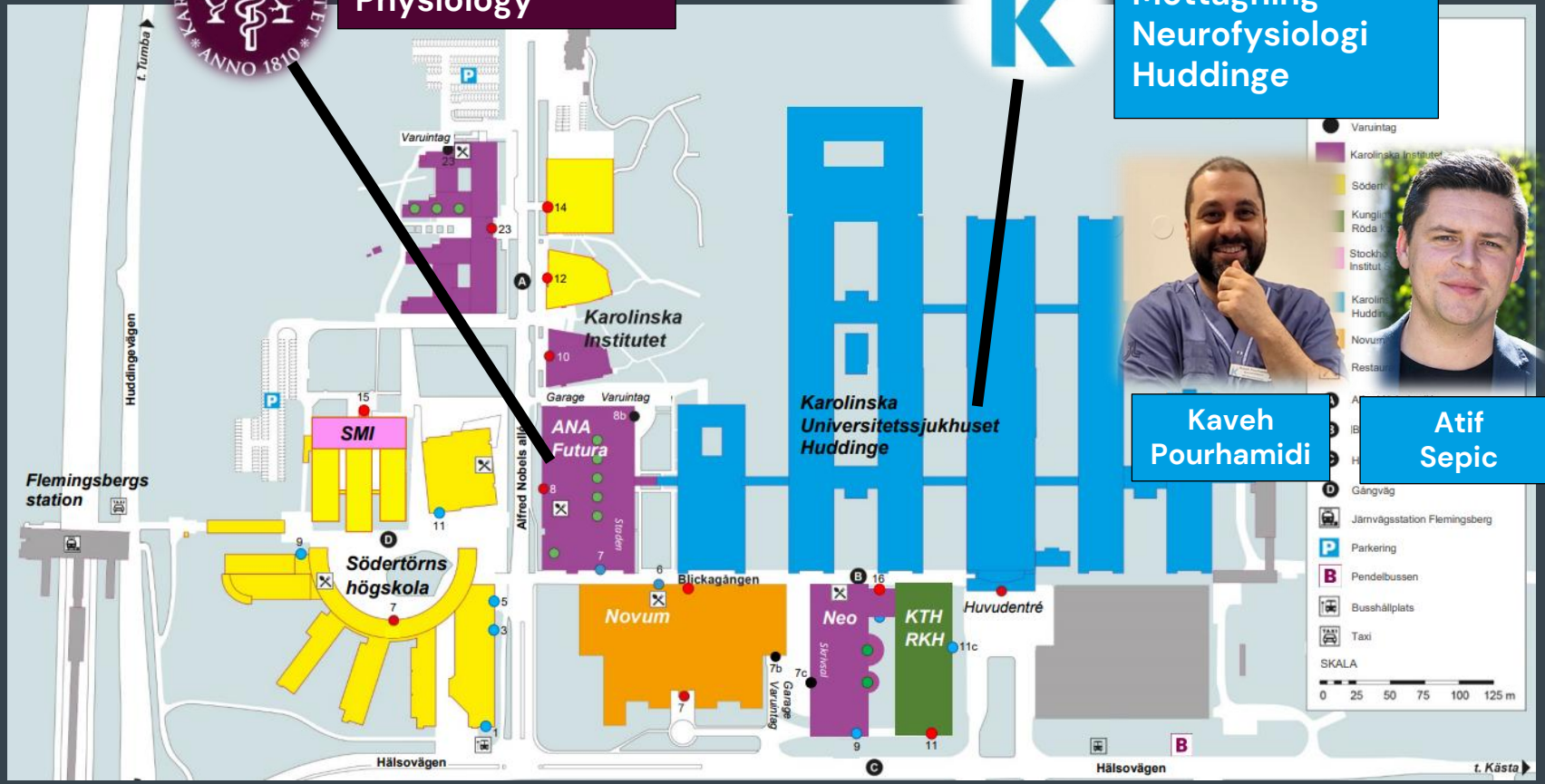
2. Faster, automated data collection (Bostock, 2016; Jacobsen et al., 2018, 2017; Garg et al., 2017)

3. Higher reproducibility and sensitivity. Stronger links with disease progression, particularly in ALS (Jacobsen et al., 2017)

4. Potential clinical relevance: outcome measure in a phase II ALS drug trial (Vucic et al., 2023)

Division of Clinical Physiology

Mottagning Neurofysiologi Huddinge



Kaveh Pourhamidi

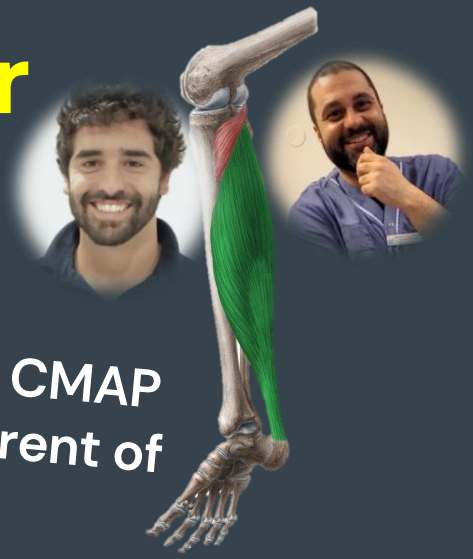
Atif Sepic

Space and environmental physiology – Rodrigo Fernandez-Gonzalo group

Our work focuses on understanding how spaceflight affects the mass and function of skeletal muscle and how this tissue interacts with other physiological systems of the human body in space. We are also very interested in developing countermeasures to offset the deleterious effect of spaceflight on the human body.

Part of the:
Department of Laboratory Medicine

Can we estimate soleus motor unit numbers with MScanFit?



Have others done it before?

Can we elicit a soleus CMAP in everyone with a current of 50 mA?

Too painful to deliver supramaximal high-frequency (2 Hz) tibial nerve stim?

Can robust stimulation-response curves be generated?

Can we generate biphasic soleus responses?

Soleus MScanFit protocol refinement

Interstimulus interval:

✗ 0.6 s

✓ 2 s (100–75% CMAP) + 1 s (75–50% CMAP) + 0.75 s (50 % – Baseline)
Protocol duration: ~ 20 min instead of ~ 6 min

Pulse width: 1 ms

Stimulating electrodes:
cathode (popliteal fossa: bar electrode with velcro)
anode (above patella: rectangular 5 x 9 cm electrode)

EMG acquisition:
monopolar

Soleus MScanF… …efin…

Interstimulus interval:

- ✗ 0.6 s
- ✓ 2 s (100–75% CMAP) + 1 s (… 0.75 …)
  Protocol duration: ~ 20 mi… …n

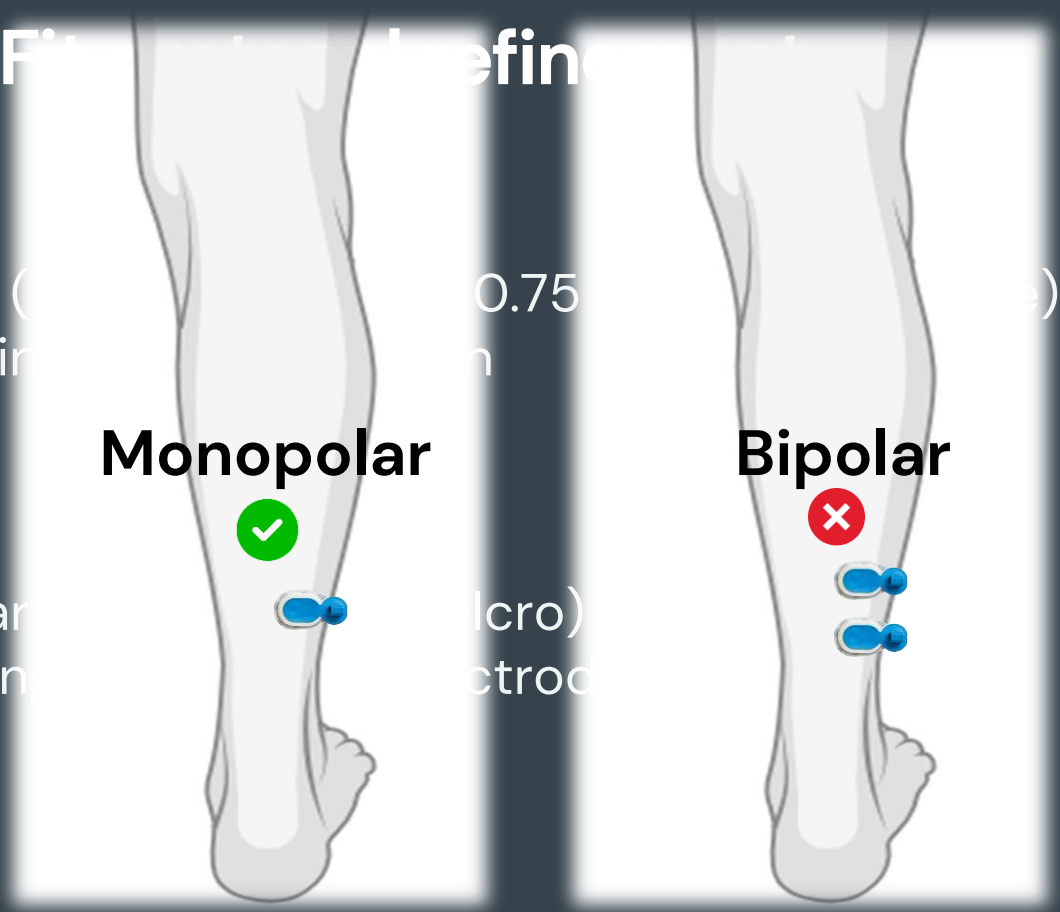
Pulse width: 1 ms

Stimulating electrodes:

cathode (popliteal fossa: bar… …lcro)
anode (above patella: rectan… …ctroc…

EMG acquisition:

monopolar



Soleus MScanFit protocol refinement

Interstimulus interval:

✗ 0.6 s

✓ 2 s (100–75% CMAP) + 1 s (75–50% CMAP) + 0.75 s (50 % – Baseline)
Protocol duration: ~ 20 min instead of ~ 6 min

Pulse width: 1 ms

Stimulating electrodes:
cathode (popliteal fossa: bar electrode with velcro)
anode (above patella: rectangular 5 x 9 cm electrode)

EMG acquisition:
monopolar
active electrode location more lateral and individualised

Soleus MScanF… …efin…

Interstimulus interval:

- ✗ 0.6 s
- ✓ 2 s (100–75% CMAP) + 1 s (… 0.75 …)
  Protocol duration: ~ 20 mi… …n

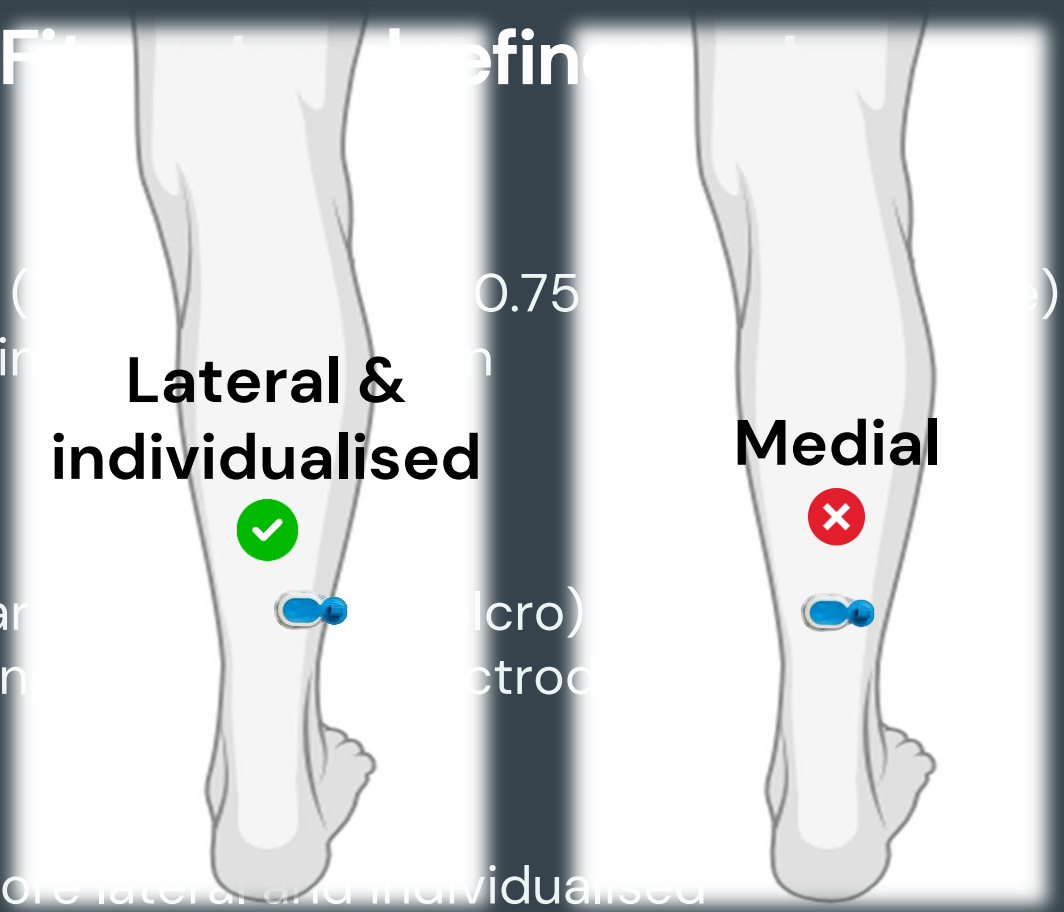
Pulse width: 1 ms

Stimulating electrodes:

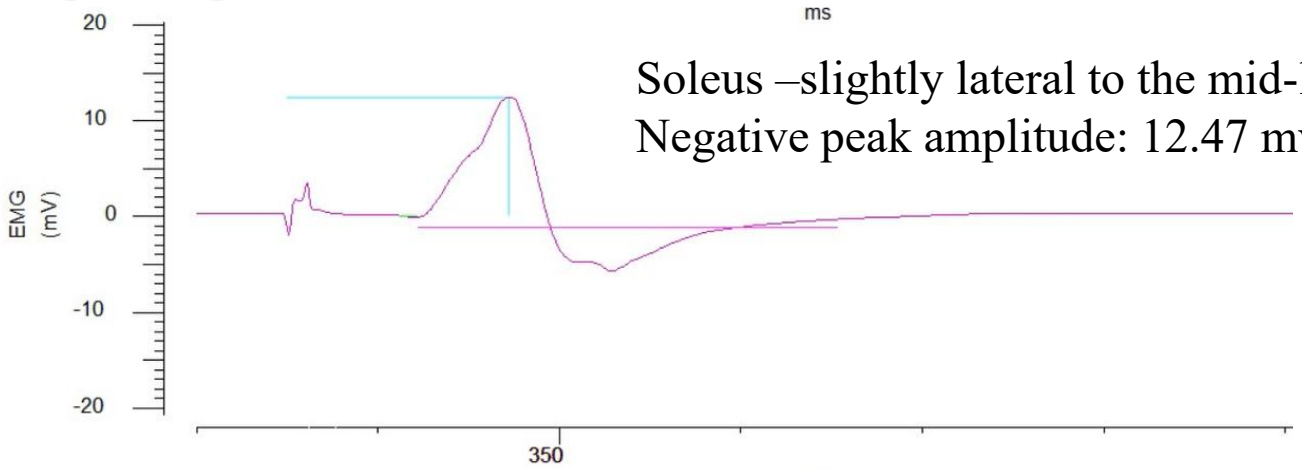
cathode (popliteal fossa: bar… …lcro)
anode (above patella: rectan… …ctroc…

EMG acquisition:

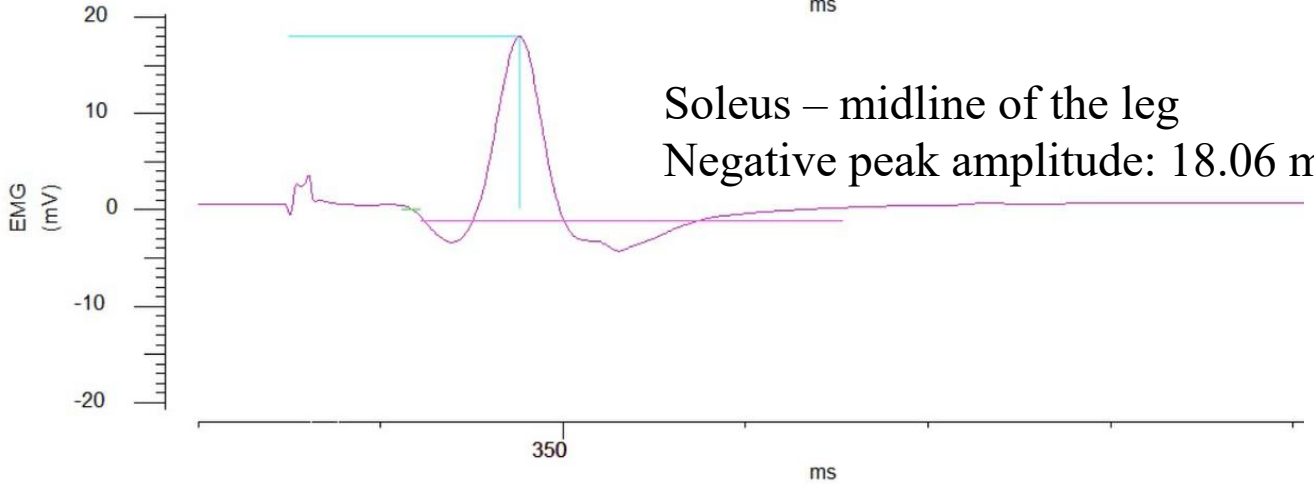
monopolar
active electrode location mo… …lateral and individualised



Participant 1 (pilot data)

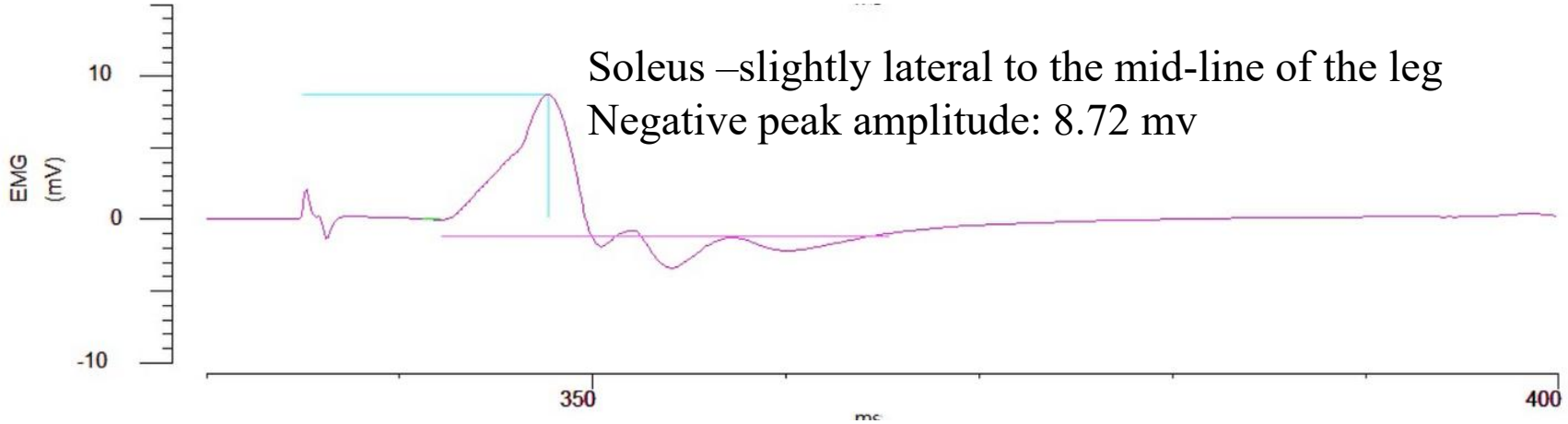


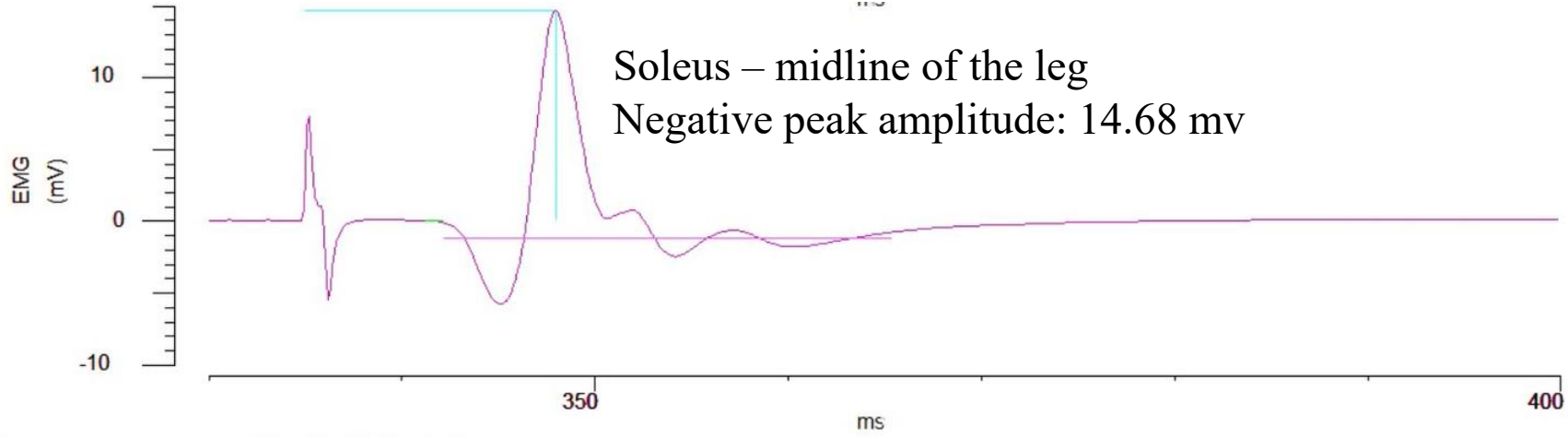
Soleus –slightly lateral to the mid-line of the leg
Negative peak amplitude: 12.47 mv



Soleus – midline of the leg
Negative peak amplitude: 18.06 mv

Participant 2 (pilot data)





Soleus MScanFit protocol refinement

Interstimulus interval:

- ✗ 0.6 s
- ✓ 2 s (100–75% CMAP) + 1 s (75–50% CMAP) + 0.75 s (50 % – Baseline)
  Protocol duration: ~ 20 min instead of ~ 6 min

Pulse width: 1 ms

Stimulating electrodes:
cathode (popliteal fossa: bar electrode with velcro)
anode (above patella: rectangular 5 x 9 cm electrode)

Hatice Tankisi

EMG acquisition:
monopolar
active electrode location more lateral and individualised

Does short-term muscle disuse induce motor unit loss?

Microgravity

Limb immobilisation (injury / post-surgery)

Prolonged bed rest

Does short-term muscle disuse induce motor unit loss?

- Rats that were sent to space lost motoneurons (D'Amelio et al., 1992)
- Earth-based analogues: signs of muscle denervation via EMG changes and molecular biomarkers (Sarto et al., 2022; 2025)
- Two human studies: no change in MUNE (Attias et al., 2020; Zeppelin et al., 2023)
  - Low-risk muscles (tibialis anterior)
  - Short duration (e.g., 1 week)
  - Limitations in microgravity simulation

n = 7 (2 females)

Unloading
2 weeks of
unilateral lower
limb suspension

n = 7 (2 females)

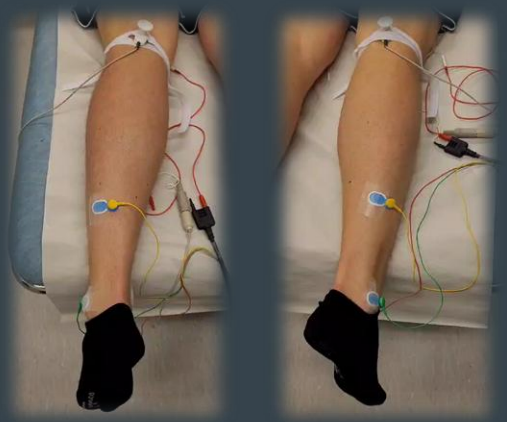
Unloading
2 weeks of unilateral lower limb suspension

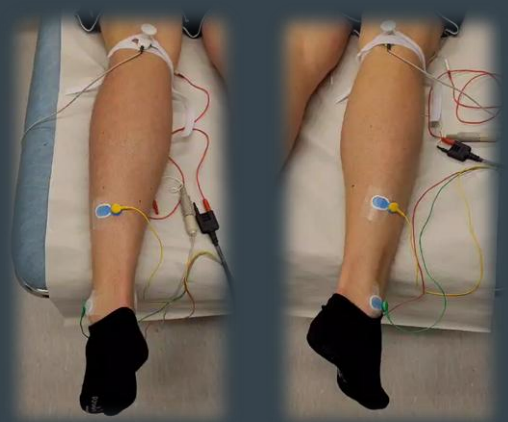
n = 7 (2 females)

Pre-unloading
MUNE testing
Control + Unloaded leg

Unloading
2 weeks of unilateral lower limb suspension

n = 7 (2 females)

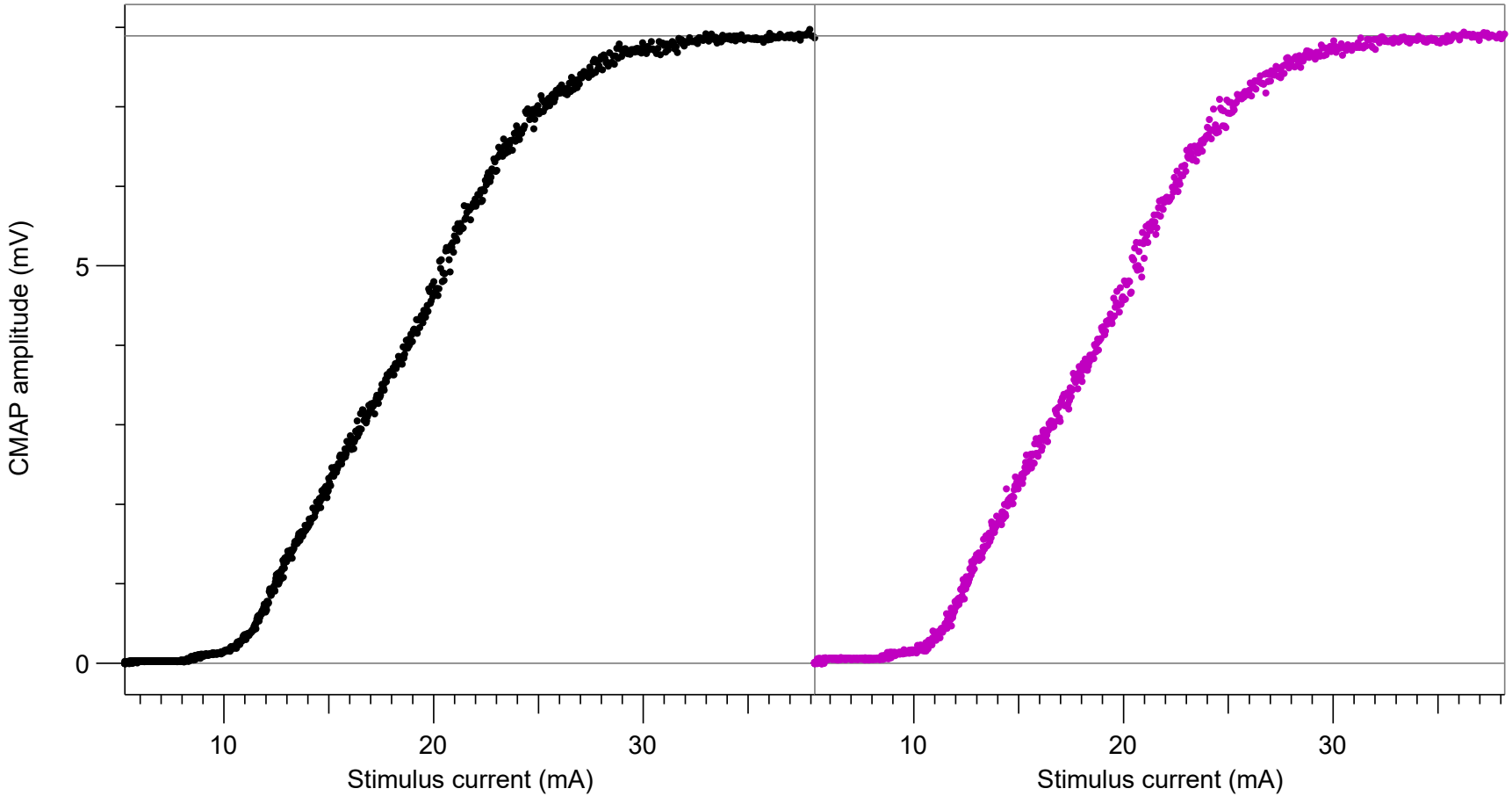


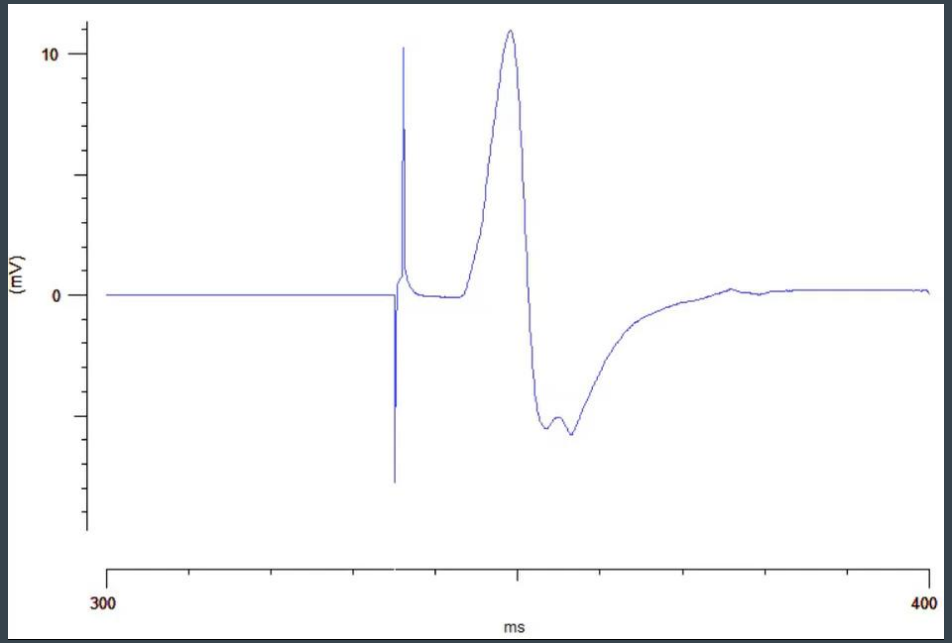


Pre-unloading
MUNE testing
Control + Unloaded leg

Unloading
2 weeks of unilateral lower limb suspension

Post-unloading
MUNE testing
Control + Unloaded leg


CMAP amplitude (mV)
5
0
10
20
30
Stimulus current (mA)
10
20
30
Stimulus current (mA)

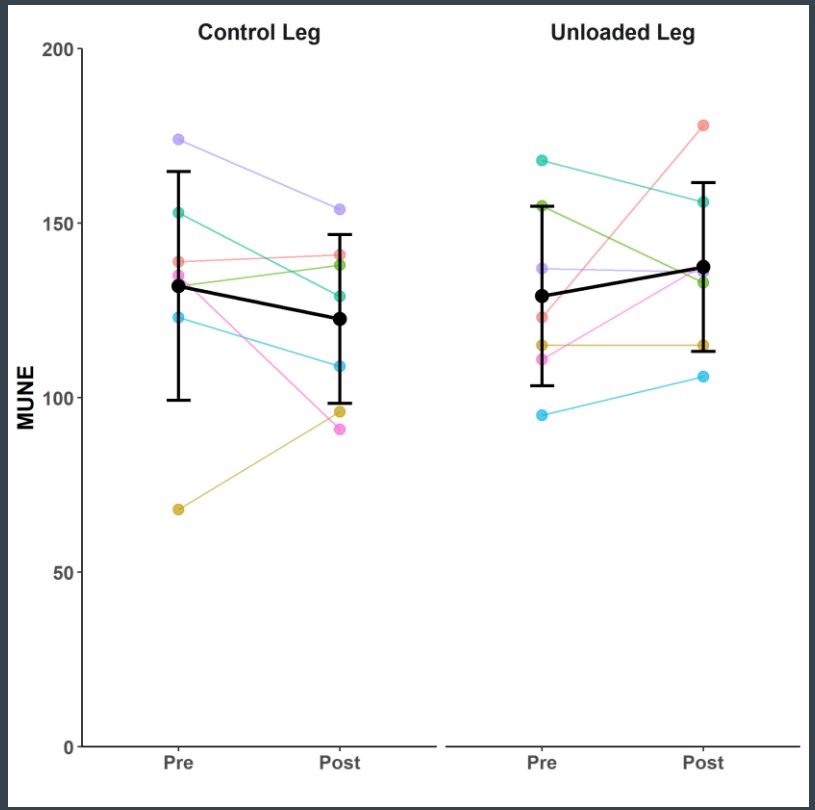


Maximum current amplitude:
42.3 ± 7.3 mA (range: 25–50)

MScanFit protocol duration:
20.8 ± 3.0 min (14.7–28.5)

Number of stimuli:
1080 ± 132 (878–1379)

No changes in motor unit number

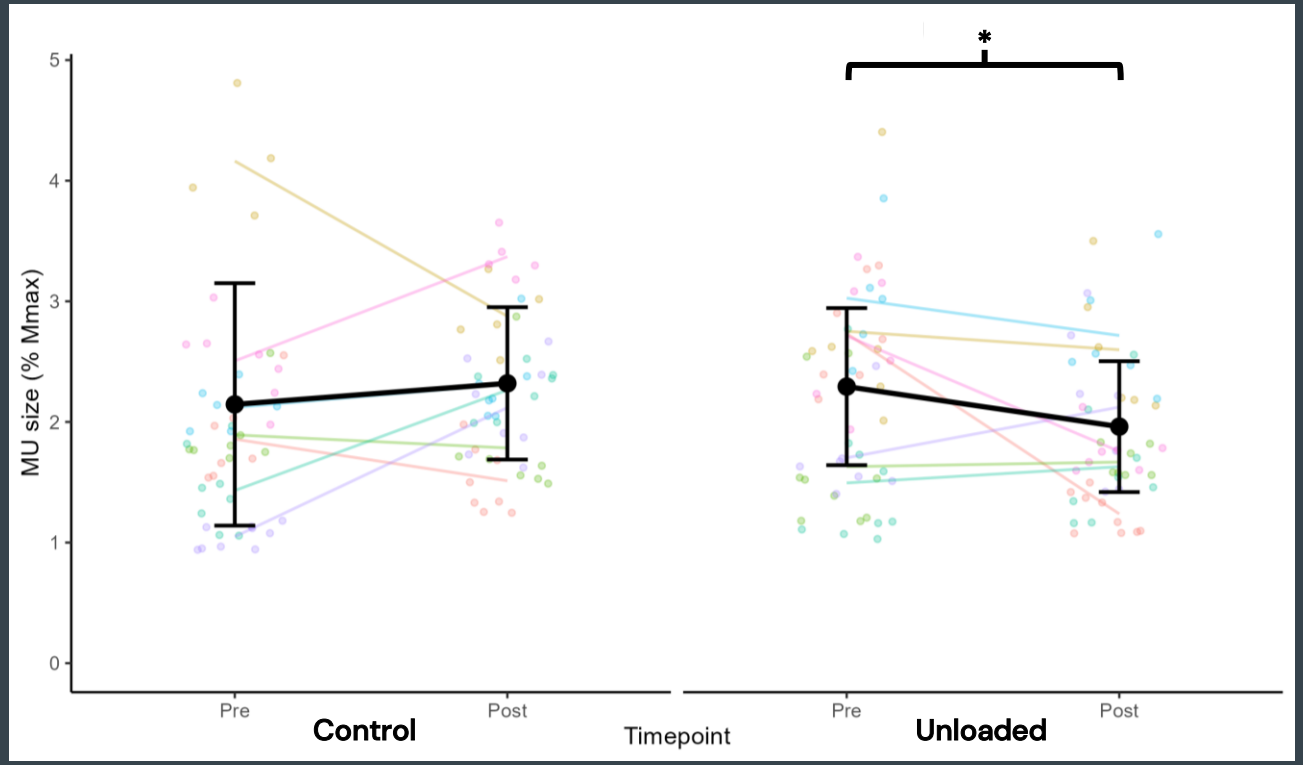


Pre-ULLS control leg: 132 ± 33
Post-ULLS control leg: 123 ± 24

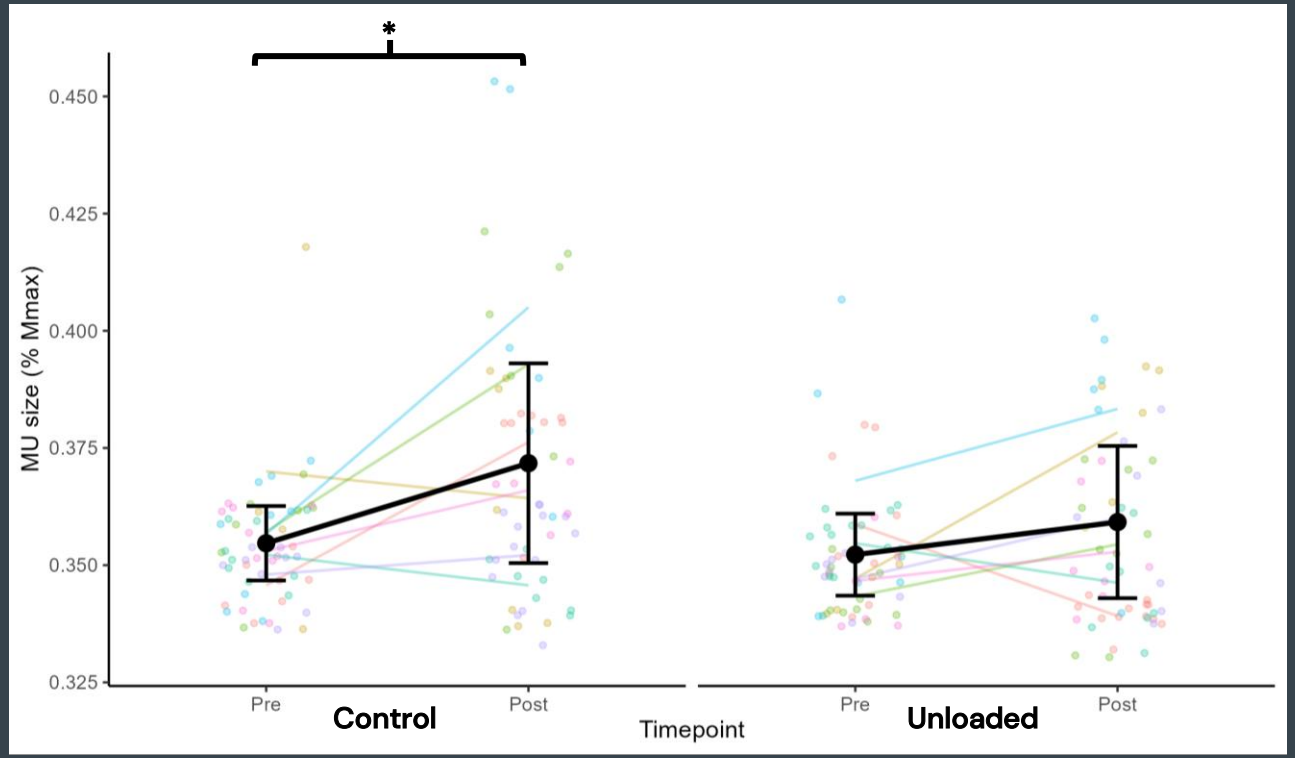
Pre-ULLS unloaded leg: 129 ± 26
Post-ULLS unloaded leg: 137 ± 24

Fit error: 3.68 ± 1.89 % (1.29–8.43)
Only two trials above 6%.

Relative size of largest units decreased in the unloaded leg



Relative size of the smallest units increased in the control leg



CONCLUSIONS

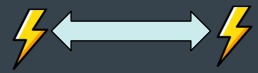
- No evidence of motor unit loss following two weeks of unloading
- Observed shifts in motor unit size suggest early alterations in motor unit properties
  - Larger units -> Smaller in unloaded leg
  - Smaller units -> Larger in control leg
- Larger cohorts needed to confirm whether MUNE approaches can be sufficiently sensitive to detect changes in motor unit size after muscle disuse

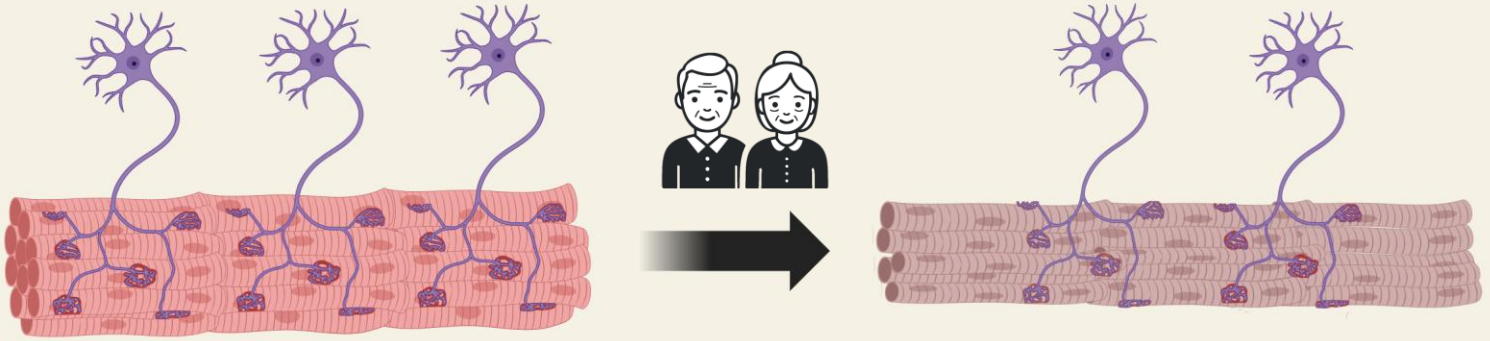
REMINDER!

We are only touching the surface with surface EMG

- Small pick up area
- Biased towards more superficial and larger motor units

FUTURE DIRECTIONS (MUNE) AT KAROLINSKA

- Increase sample size 
- Reliability of CMAP-scan MUNE approaches in plantar flexors 
- Motor unit loss with ageing 



Motor unit loss and reinnervation
Motor unit number estimation (MUNE)

Neural function

High-density electromyography: intrinsic motoneuron excitability, motor unit firing frequency and conduction velocity
Skin biopsy: Epidermal nerve fiber density

Muscle function

Skeletal muscle biopsy: neuromuscular junction stability, fibre type/size, satellite cell and capillary network evaluation, gene expression via RNA sequencing

Physical function

Fitness testing: muscle strength, muscle endurance, balance, and aerobic capacity

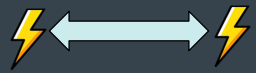
Physical activity, lifestyle, and morbidity

Questionnaires

Muscle and body composition

MRI: muscle size, muscle mass, muscle fat infiltration

FUTURE DIRECTIONS (MUNE) AT KAROLINSKA

- Increase sample size 
- Reliability of CMAP-scan MUNE approaches in plantar flexors 
- Motor unit loss with ageing 
- Clinical trials with MUNE as primary or secondary outcome? 
- Feasibility and utility of using MUNE in clinical practice? 

ACKNOWLEDGMENTS

Kaveh Pourhamidi
Atif Sepic
Vanessa Hallström

Rodrigo Fernandez Gonzalo
Mirko Mandic
Saul Martin-Rodriguez

Hatice Tankisi

Stefan Schneider
Constance Badali

Funding – Unloading study

Rymdstyrelsen
Swedish National Space Agency

DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center


KAROLINSKA INSTITUTET
ANNO 1810
Karolinska
Institutet