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Validation of Online Intrinsic and Reflexive Joint Impedance Estimates using Correlation with EMG Measurements

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Background

Two state-of-the-art research lines towards voluntary modulation of reflexive activity in order to reduce spasticity:

EMG-based[1]:
- Reduce muscle hyperreflexia
- Constant background activity
- Participants with spasticity

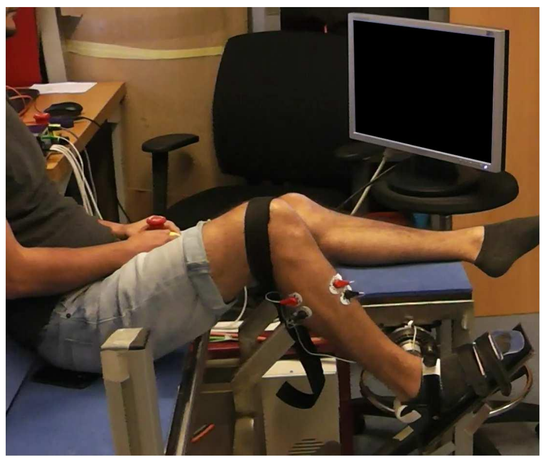
System Identification-based[2]:
- Modulation reflexive impedance
- Constant intrinsic impedance
- Able-bodied participants

Can the system identification-based paradigm also be used by participants with spasticity? Potential improvements w.r.t. EMG:
- Participant comfort
- Applicability
- Target multiple muscles
- Faster training effects

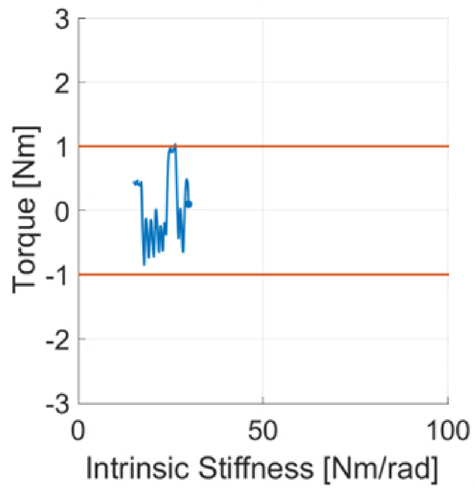
Aim

Investigate linear association between the independently measured EMG- and system identification-based paradigms:
- Background EMG activity ⇔ Intrinsic joint stiffness
- Reflex EMG activity ⇔ Reflexive activity

Protocol



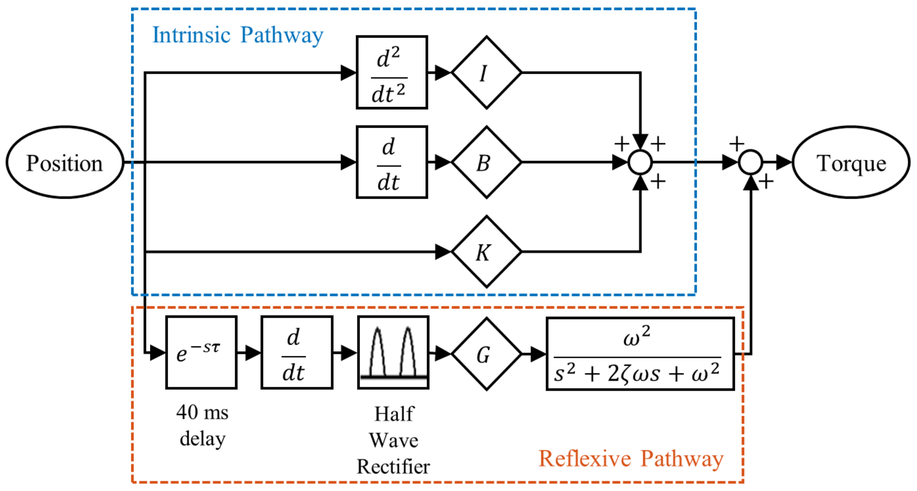
- 3 male able-bodied subjects
- 1-DOF perturbations in sagittal plane of ankle joint
- Train modulation intrinsic stiffness & reflexive activity
- Keep behavior constant for several 60s periods



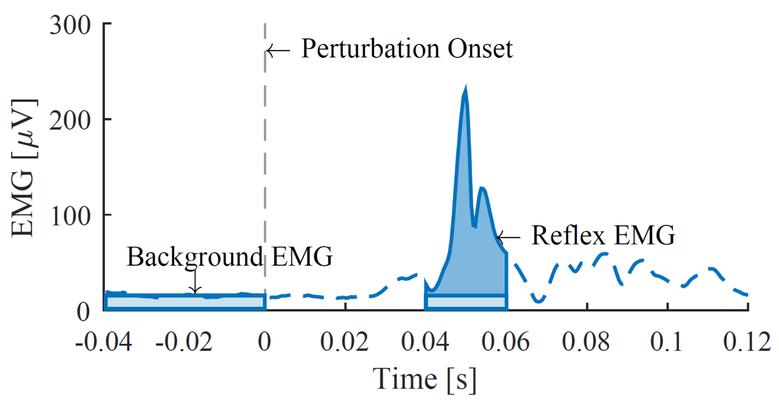
- Feedback on torque (y-axis) and intrinsic stiffness or reflexive activity (x-axis)
- Neutral or plantarflexion torque task
- Co-contraction allowed

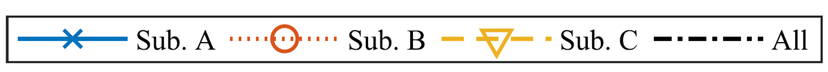
Methods & Results

System Identification

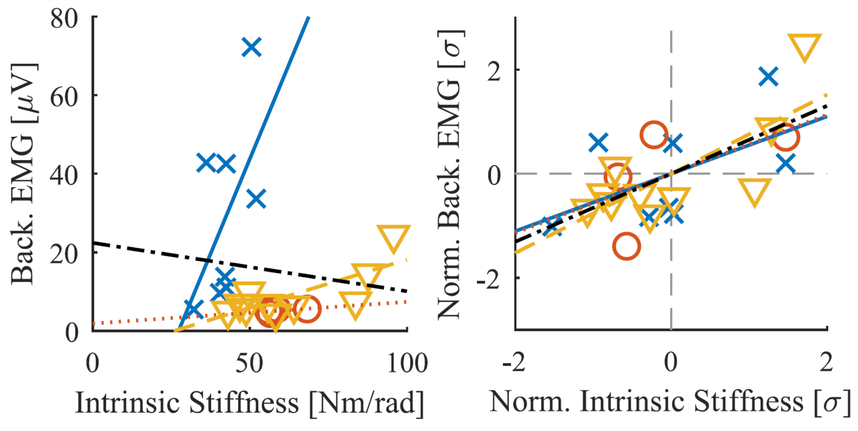


EMG

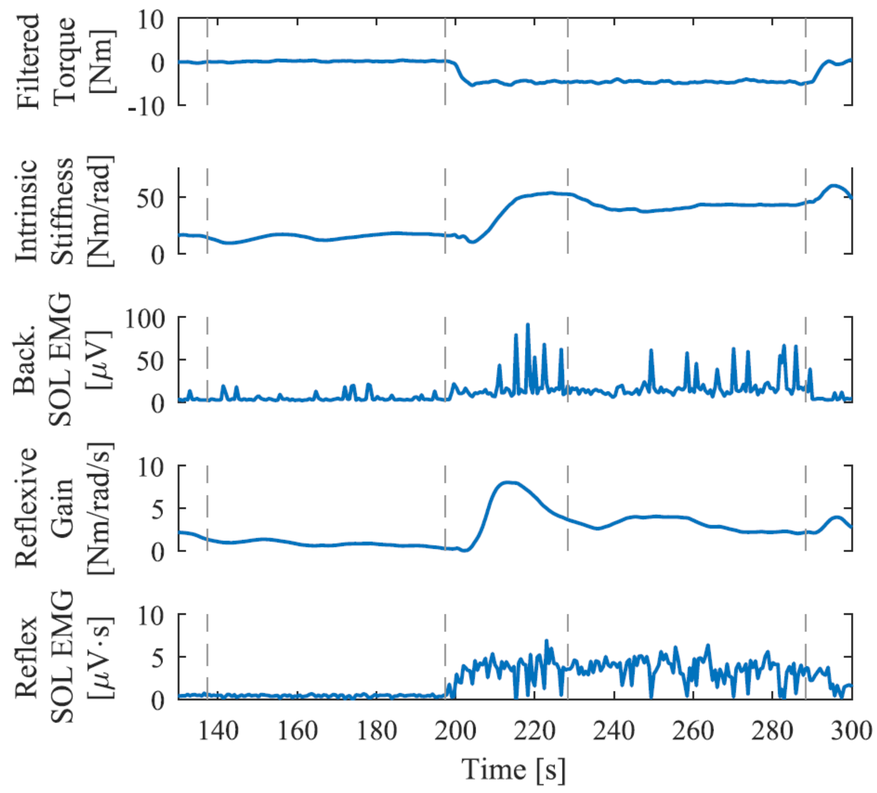




Normalization per subject



Consecutive 60s periods with constant subject behavior show the following associations:
- Background EMG Soleus ⇔ Intrinsic stiffness
- Reflex EMG Soleus ⇔ Reflexive gain



Correlation coefficient using data normalized per subject:

Torque	Intrinsic 0 Nm (*N* = 33)	Intrinsic -5 Nm (*N* = 22)	Reflexive 0 Nm (*N* = 33)	Reflexive -5 Nm (*N* = 22)
SOL	0.93 [0.85, 0.97]	0.70 [0.44, 0.87]	0.78 [0.62, 0.87]	0.57 [0.20, 0.77]
TA	0.88 [0.78, 0.95]	0.70 [0.19, 0.87]	0.55 [0.27, 0.75]	0.18 [-0.11, 0.45]
GL	0.91 [0.83, 0.96]	0.36 [-0.18, 0.69]	0.75 [0.58, 0.85]	0.56 [0.21, 0.76]
GM	0.80 [0.56, 0.92]	0.65 [0.32, 0.82]	0.82 [0.67, 0.90]	0.46 [0.13, 0.67]

95% confidence intervals computed for four lower leg muscles and two torque target, via non-parametric bootstrap, show:
- Up to 86% shared variance for intrinsic pathway
- Up to 67% shared variance for reflexive pathway

Conclusions

Valid to use system identification-based approach in training paradigm to reduce muscle hyperreflexia give the large linear association between independent system identification and EMG measures.

[1] A. K. Thompson, F. R. Pomerantz, and J. R. Wolpaw, "Operant Conditioning of a Spinal Reflex Can Improve Locomotion after Spinal Cord Injury in Humans," *Journal of Neuroscience*, vol. 33, no. 6, pp. 2365–2375, 2013.
[2] D. Ludvig and R. E. Kearney, "Real-time Estimation of Intrinsic and Reflex Stiffness," *IEEE Transactions on Biomedical Engineering*, vol. 54, no. 10, pp. 1875–1884, 2007.

Future Research

Recommendations for using system identification measures in training to reduce muscle hyperreflexia:
- Neutral torque task
- Focus on calf muscles

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