Multi-Task Learning for Joint Impedance Estimation

Nana Porter-Honicky[1,3]  , Elliott Rouse[1,2] 

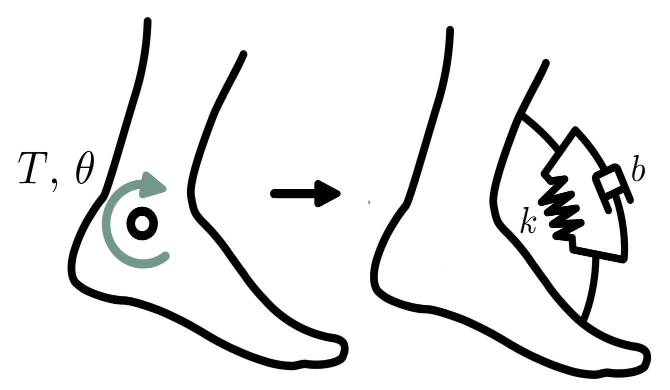
[1] Department of Mechanical Engineering, University of Michigan
[2] Department of Robotics, University of Michigan
[3] School of Kinesiology, University of Michigan

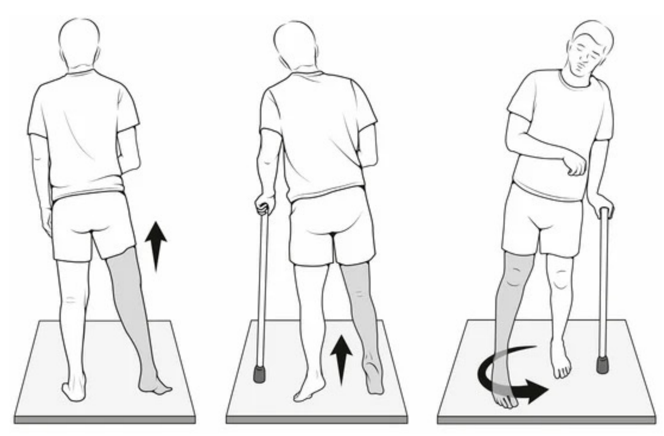
NEUROBIONICS

What is biological joint impedance?

$$T_p = I\ddot{\theta}_p + b\dot{\theta}_p + k\theta_p$$

- A mechanical model of the inertia $\mathbf{I}$, damping $\mathbf{b}$, and stiffness $\mathbf{k}$ of a joint [1,2]



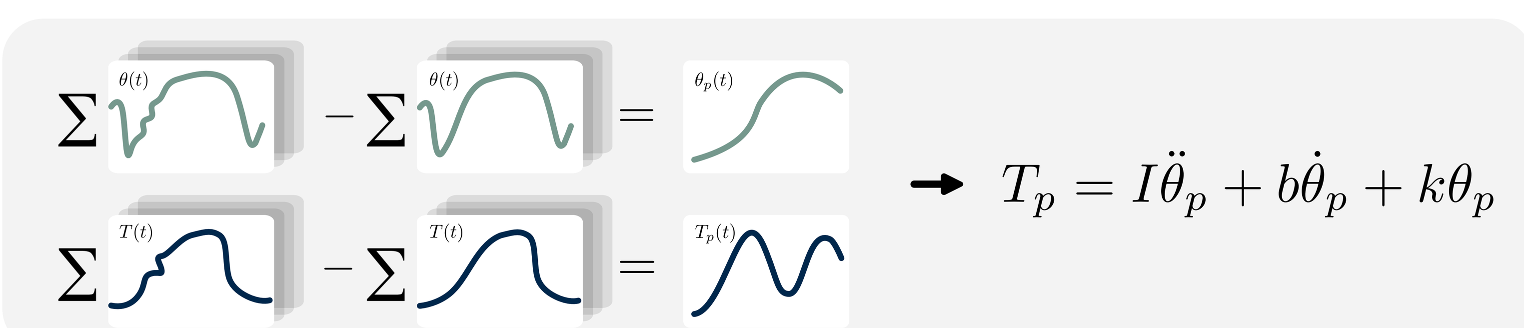


(Nesi et al., 2023)

- Impedance is useful tool in understanding gait deficits like hypertonia, spasticity, and paresis [3]

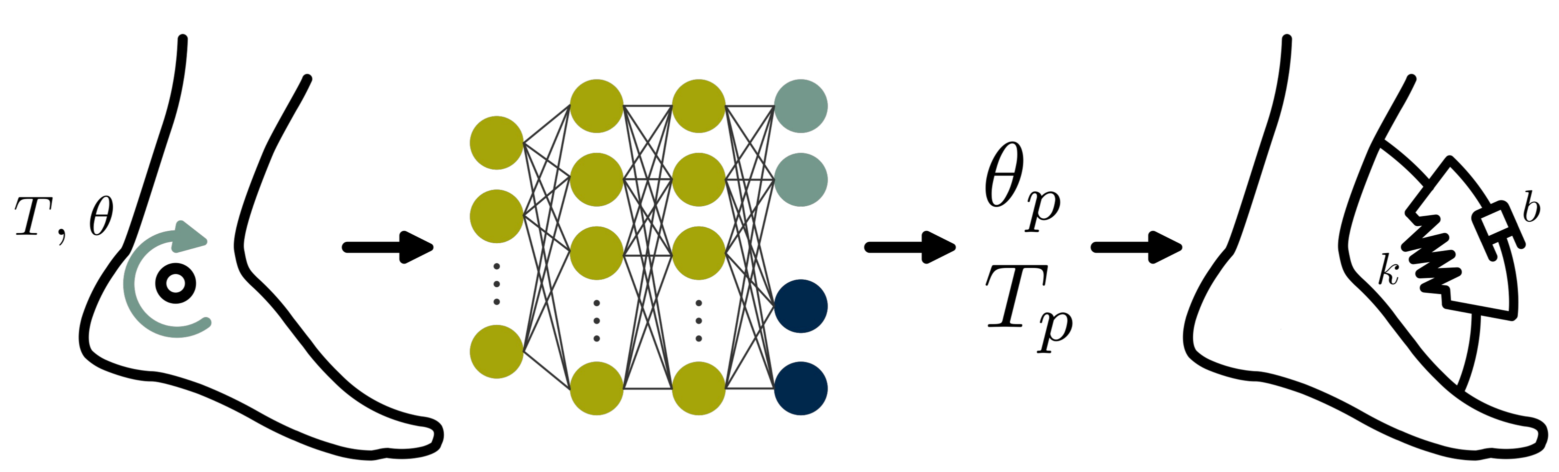
Why is it so hard to measure?

- Impedance is task and phase dependent [2]
- Requires a perturbation [1]
- Requires hundreds of trials of both perturbed and unperturbed gait [2]

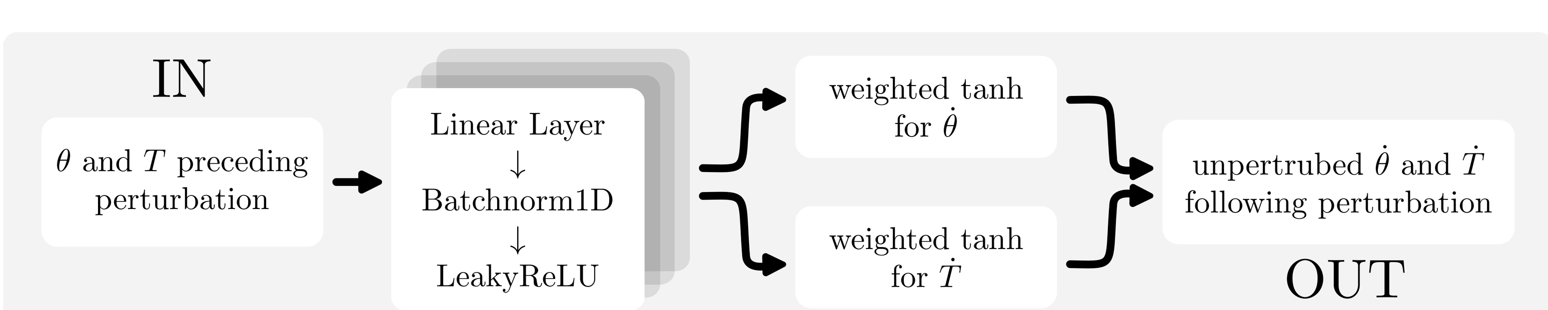


- Currently estimated using a bootstrap sampling method

How do we get around this?



Designing the model



- Models trained on kinematic and kinetic data from previous impedance estimation studies [2,3]
- Simple feed-forward neural network structure

$$\mathcal{L}^{\text{train}}(\theta, \hat{\theta}, T, \hat{T}) := \alpha_T \ell_\delta(\hat{T}, T) + \alpha_{\ddot{\theta}} \ell_\delta(\ddot{\hat{\theta}}, \ddot{\theta}) + \alpha_{\dot{\theta}} \ell_\delta(\dot{\hat{\theta}}, \dot{\theta}) + \alpha_\theta \ell_\delta(\hat{\theta}, \theta)$$

$$T_p = I\ddot{\theta}_p + b\dot{\theta}_p + k\theta_p$$

- Loss function designed to look like the governing impedance equation

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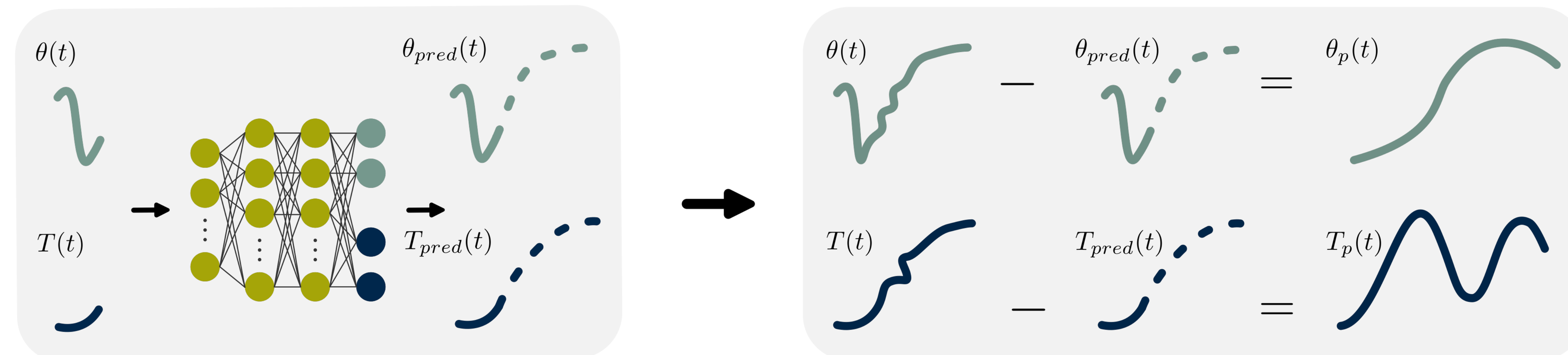
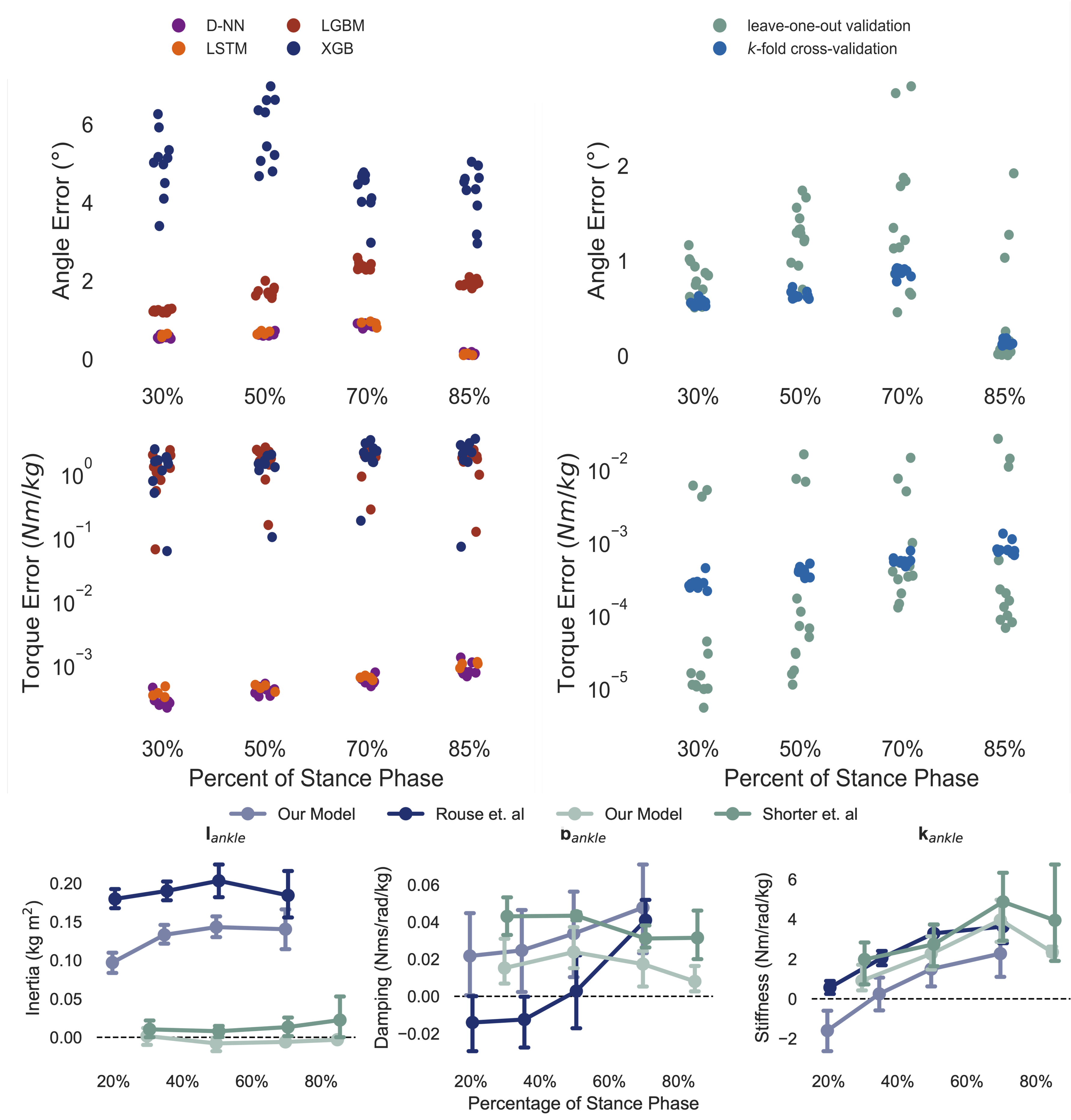
Using our model to estimate impedance



Results



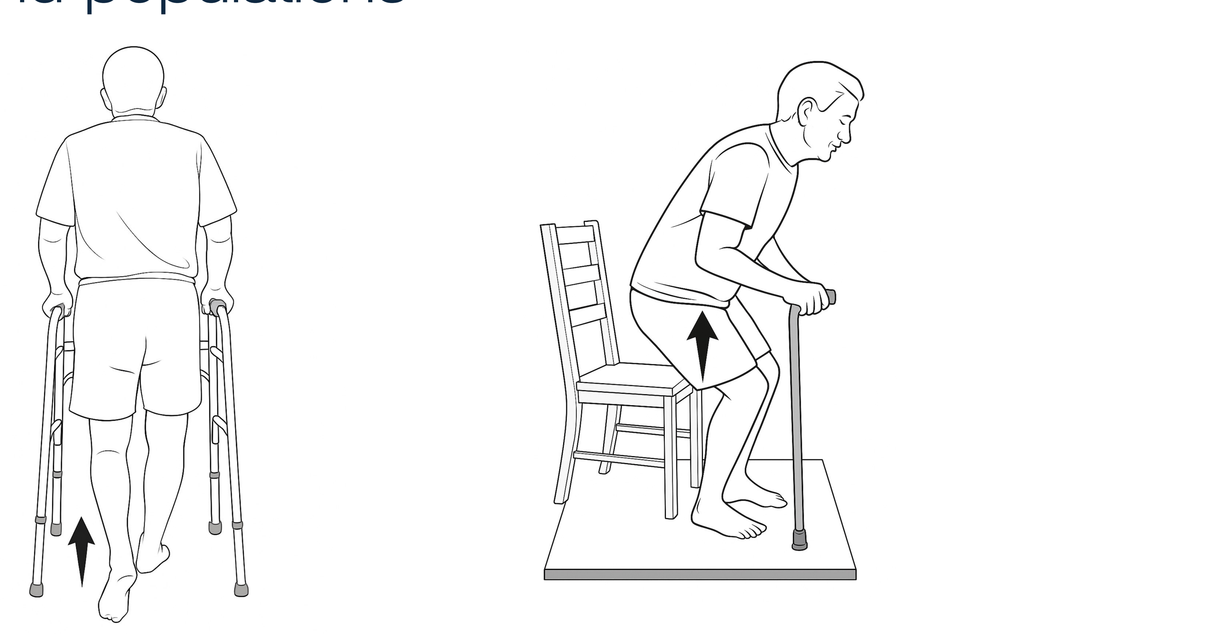
Intraclass Correlation Coefficient				
Dataset	% stance	I	b	k
Rouse et al. [1]	20	0.37	0.30	0.21
	35	0.35	0.28	0.30
	50	0.41	0.37	0.15
	70	0.42	0.12	0.31
Shorter at al. [3]	30	0.64	0.59	0.52
	50	0.96	0.14	0.82
	70	0.83	0.64	0.67
	85	0.59	0.67	0.59

Variance Accounted For	
Method	VAF (%)
Rouse et. Al [1]	98 ± 1.2
Shorter et. Al [3]	97 ± 3.0
Lee at. Al [5]	97 ± 1.0
Van Der Kooji et. al [6]	77
This work (k-fold)	98 ± 4.6
This work (leave-one-out)	96 ± 10.3

- Highly accurate model predictions
- Estimates follow published trends with notable acceptations

Implications

- Reduced data needs allow for impedance estimates on more tasks and populations



References

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