Identification of Joint Impedance

tools for understanding the human motion system, treatment selection and evaluation

Lecture 12 SIPE 2010
Case Studies

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Mission: development of SIPE technology to analyze the human neuromuscular control system

LUMC

Laboratory for Kinematics and Neuromechanics

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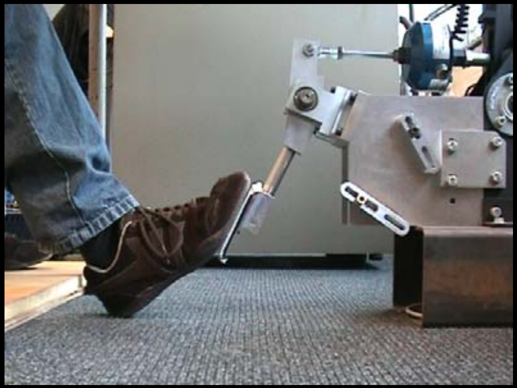
Mission: application and validation of SIPE technology in the clinical practice to improve efficacy of intervention

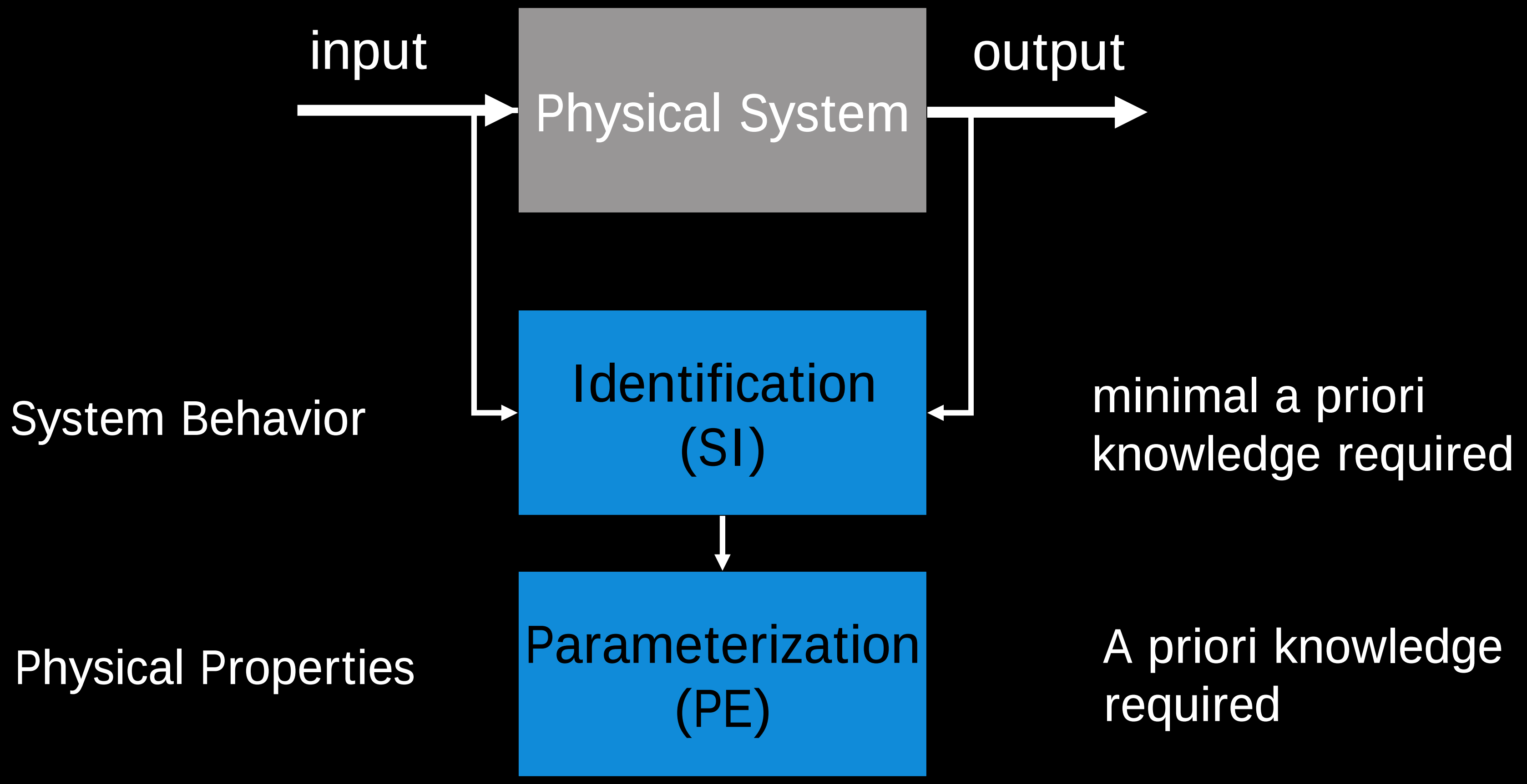
Robots for System Identification

- Mechanical energy transfer to the biological system
- Measurement of forces and movement

Robots for System Identification



System Identification & Parameter Estimation (SI-PE)



Three case studies

1. Linear SIPE: intrinsic and reflexive properties of the shoulder (1DOF)
2. Linear SIPE: ... but now for 3DOF (shoulder, elbow, wrist)
3. Nonlinear PE: intrinsic and reflexive torque of the ankle in stroke

Linear systems: Frequency domain analysis of mass-damper-spring

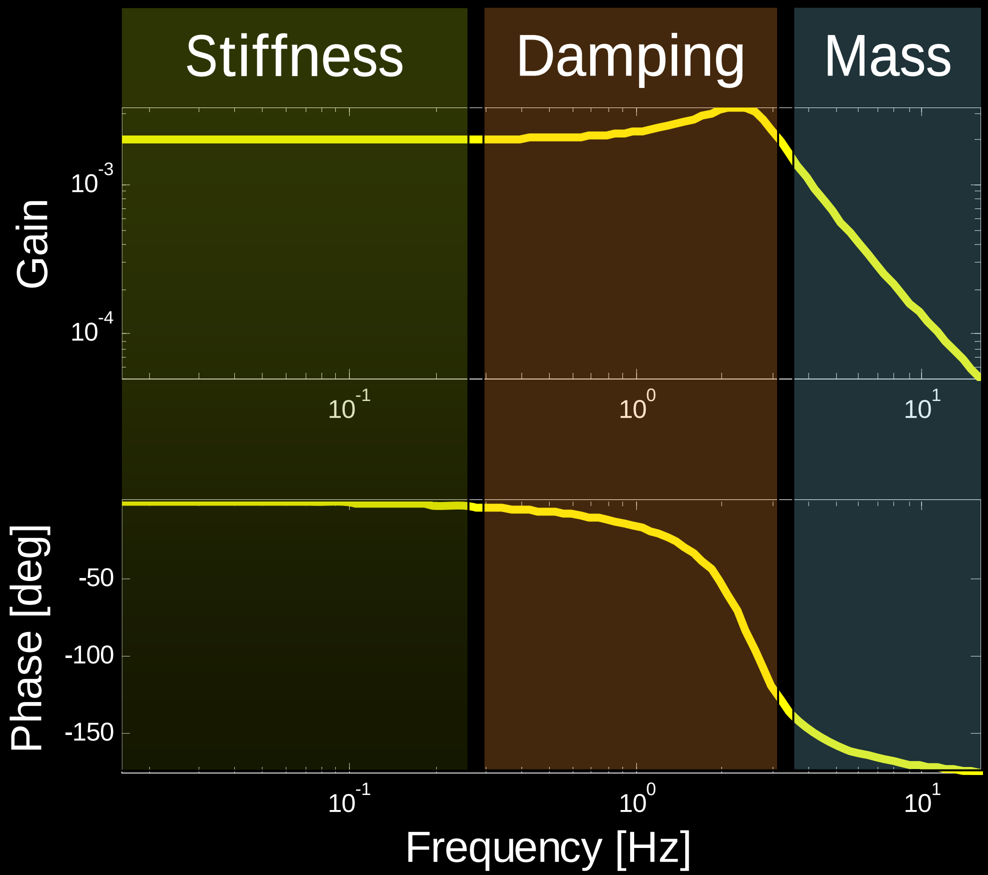
$$H(s) = \frac{1}{Ms^2 + Bs + K}$$

$$s = 2\pi f$$

- H is causal
- H is an admittance

$$\omega_0 = \sqrt{\frac{K}{M}}$$

$$\beta = \frac{B}{2\sqrt{KM}}$$



Optimal Admittance Control

- Simulations indicate that contribution of reflexes decrease with frequency of torque input.

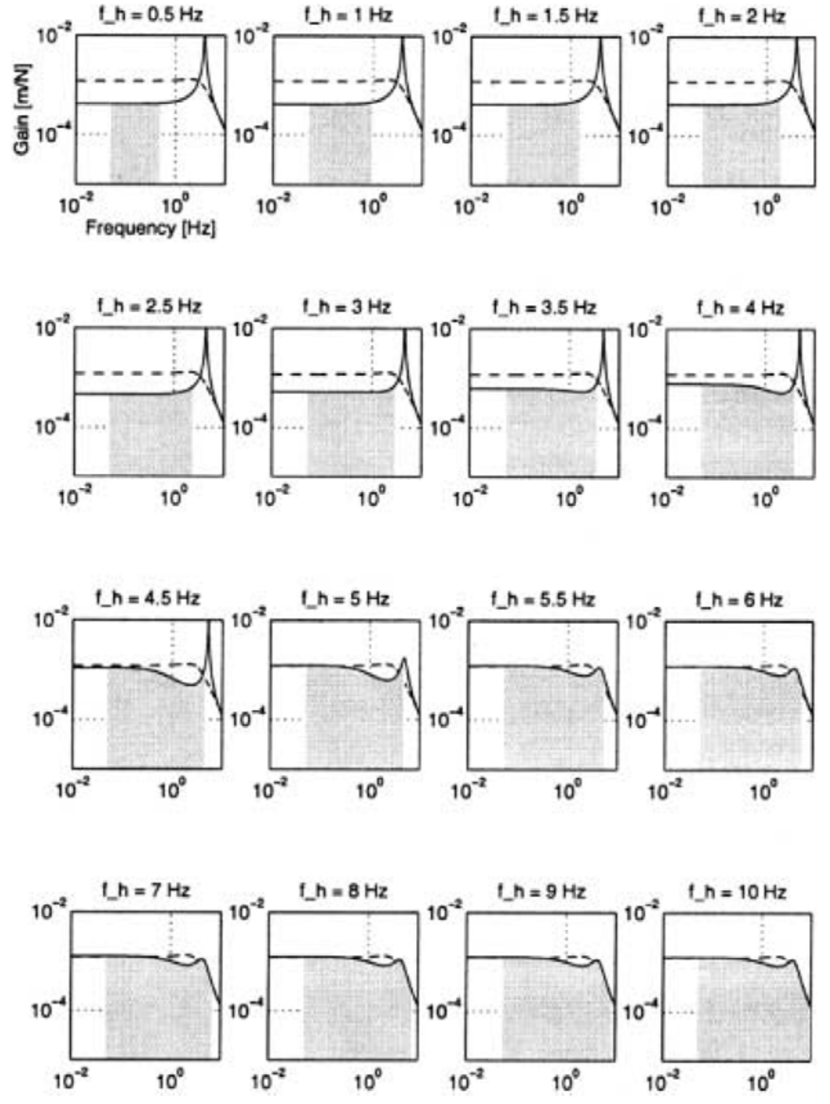


Fig. 5. Magnitudes of $H_{CL}(f)$ for NB noise type 1 with different values of f_h (*solid curves*), and for $H_c(f) = 0$, i.e. only intrinsic feedback (*dashed curves*). The *filled areas* denote the frequency range between f_l and f_h

De Vlugt et al. 2001

Short Intro to Optimal Admittance Control

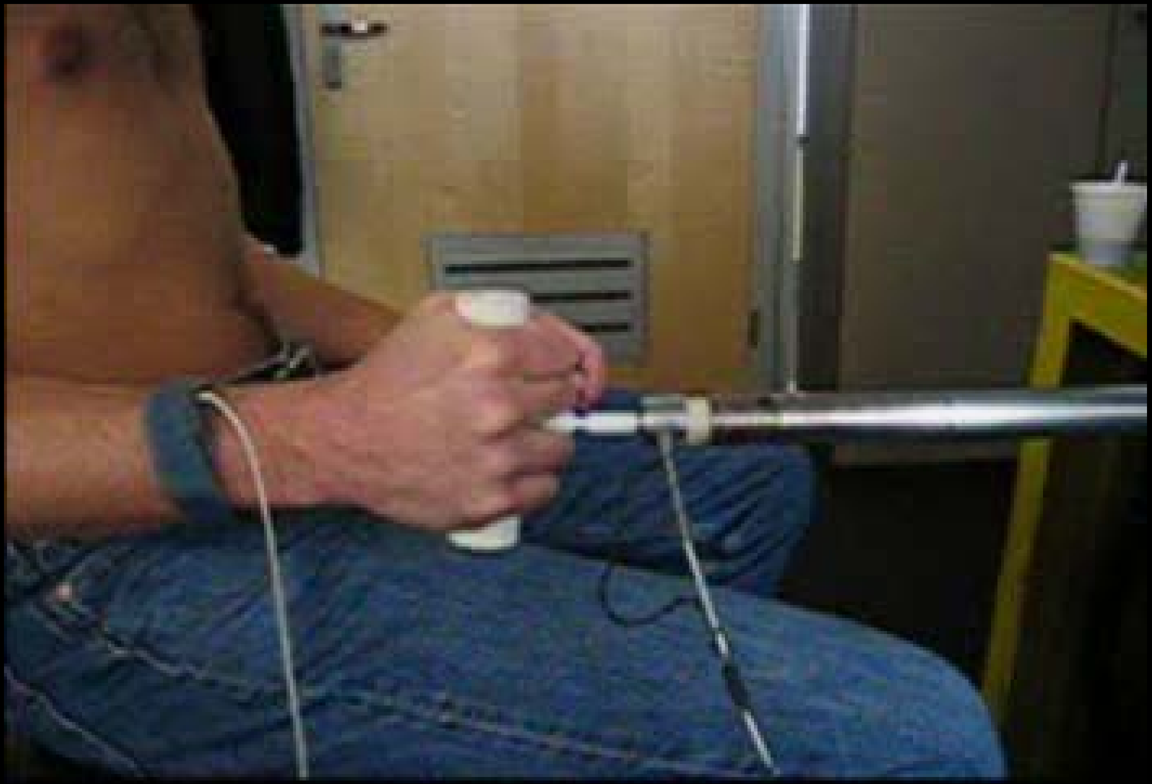
Joint Admittance

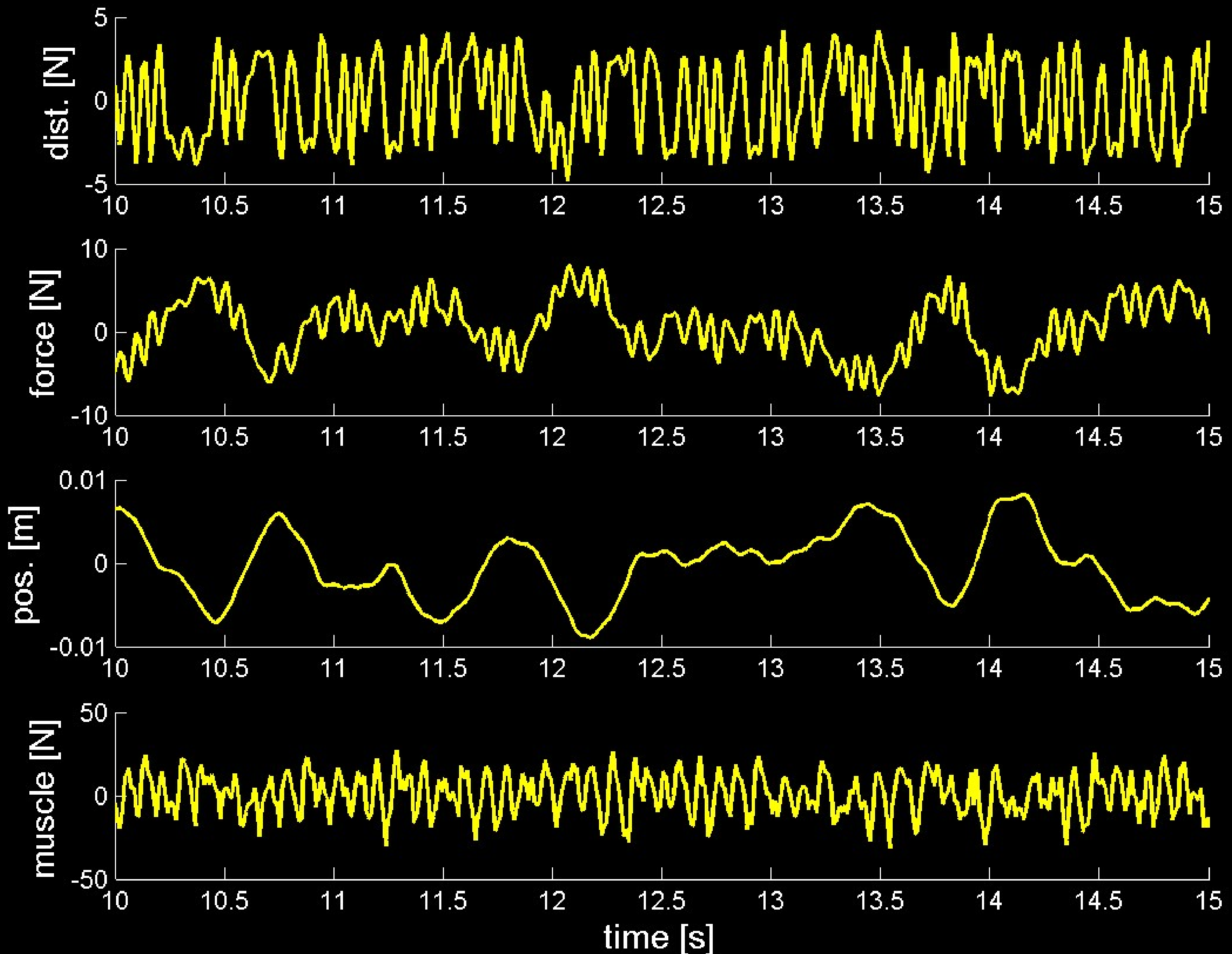
- is the dynamic relationship between joint angle and joint torque
- the result of visco-elasticity and torque generated by reflexes
- important for posture maintenance

Research Questions

- does admittance depend on the dynamic properties of external load, e.g. damping ?
- how does admittance change with joint angle?

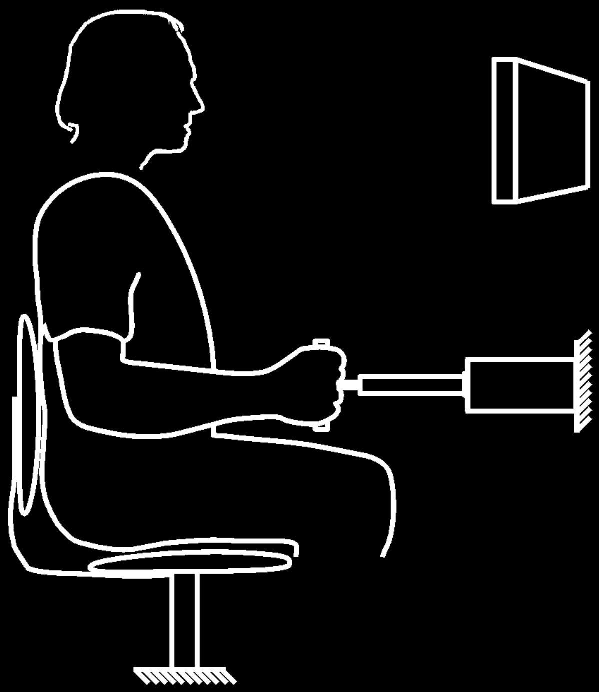
Case 1: 1DOF shoulder joint control





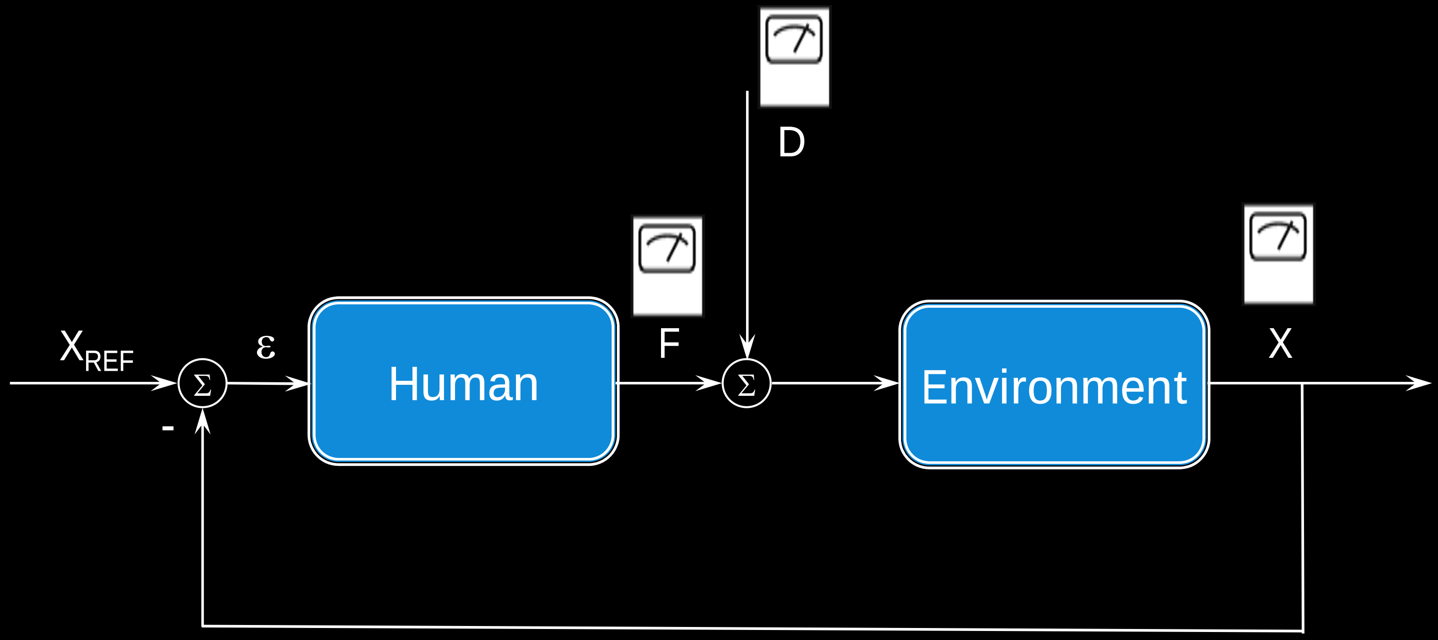
dist. [N]
5
0
-5
force [N]
10
0
-10
pos. [m]
0.01
0
-0.01
muscle [N]
50
0
-50
10
10.5
11
11.5
12
12.5
13
13.5
14
14.5
15
time [s]

Procedures

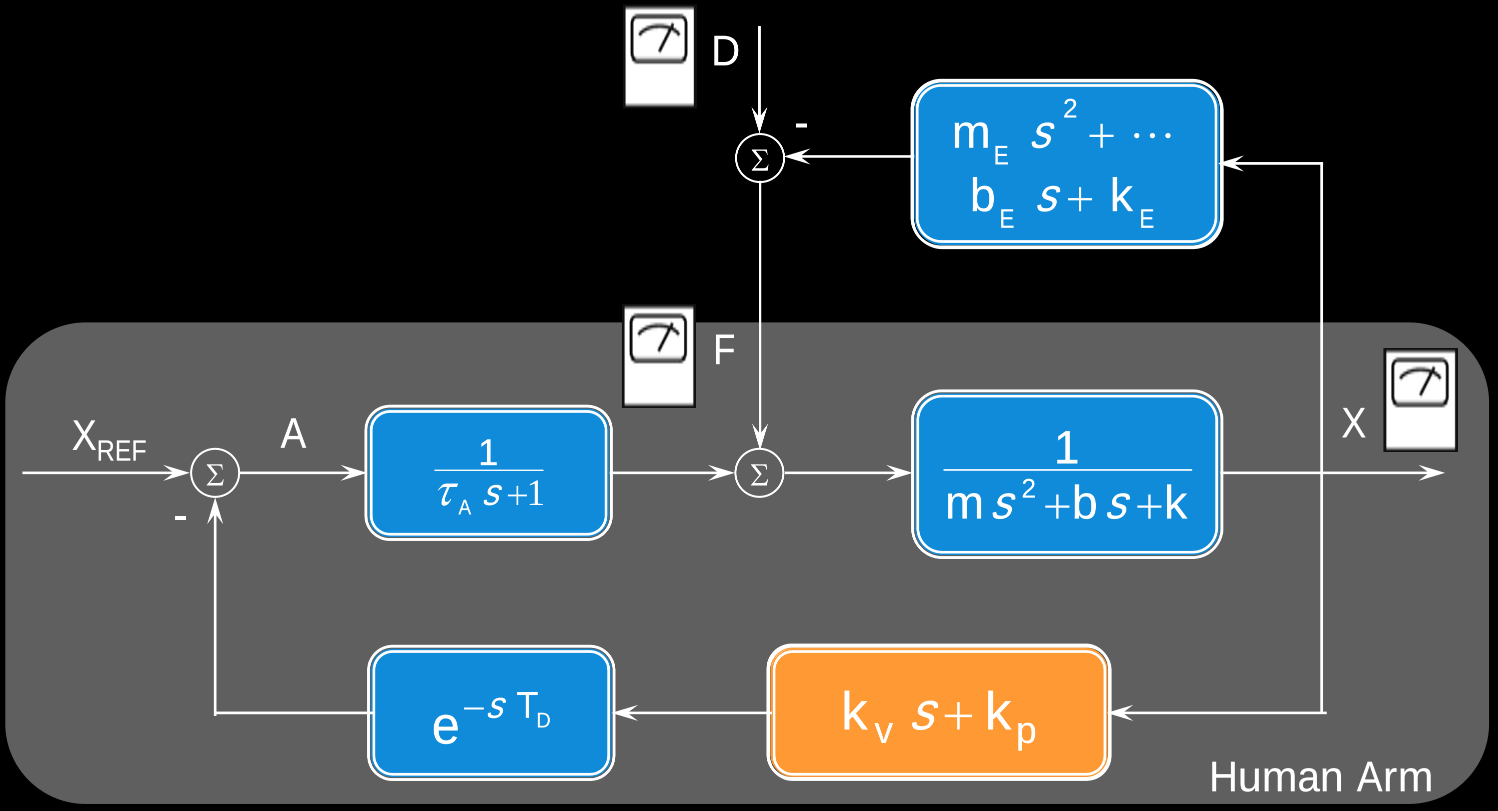


- External damping B_E: 0 – 400 Ns/m
- External mass M_E: 0.6 – 10 kg
- Unpredictable force disturbances
  - 40 s (0.1-20 Hz)
- Grip displacements ≈ 3 mm (SD)
- EMG of four shoulder muscles
- n=5 (healthy)

Force perturbations: closed loop

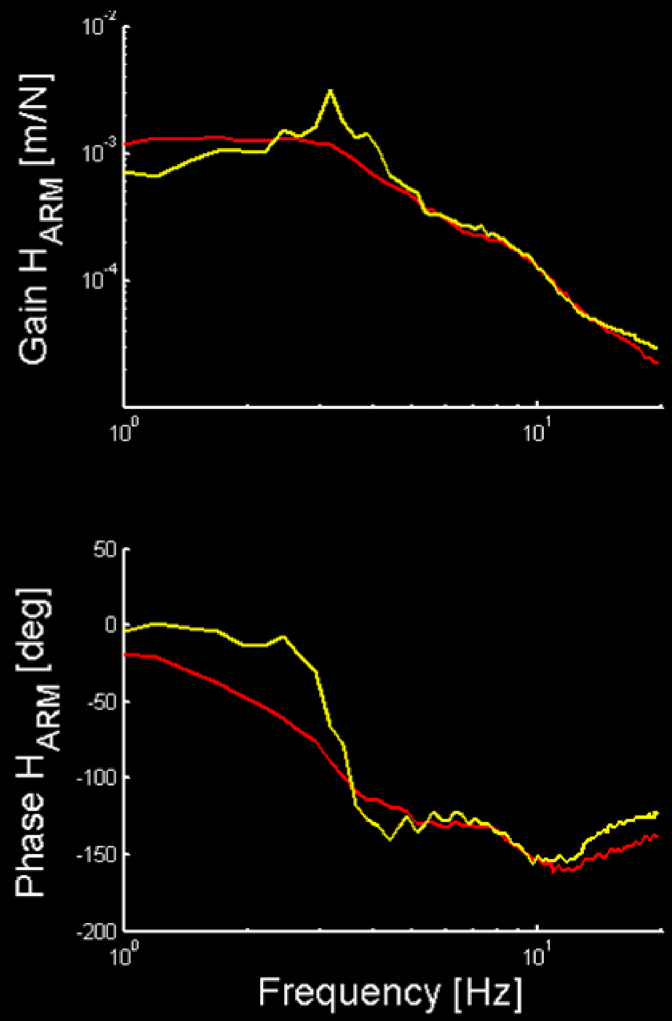


Force perturbations: closed loop

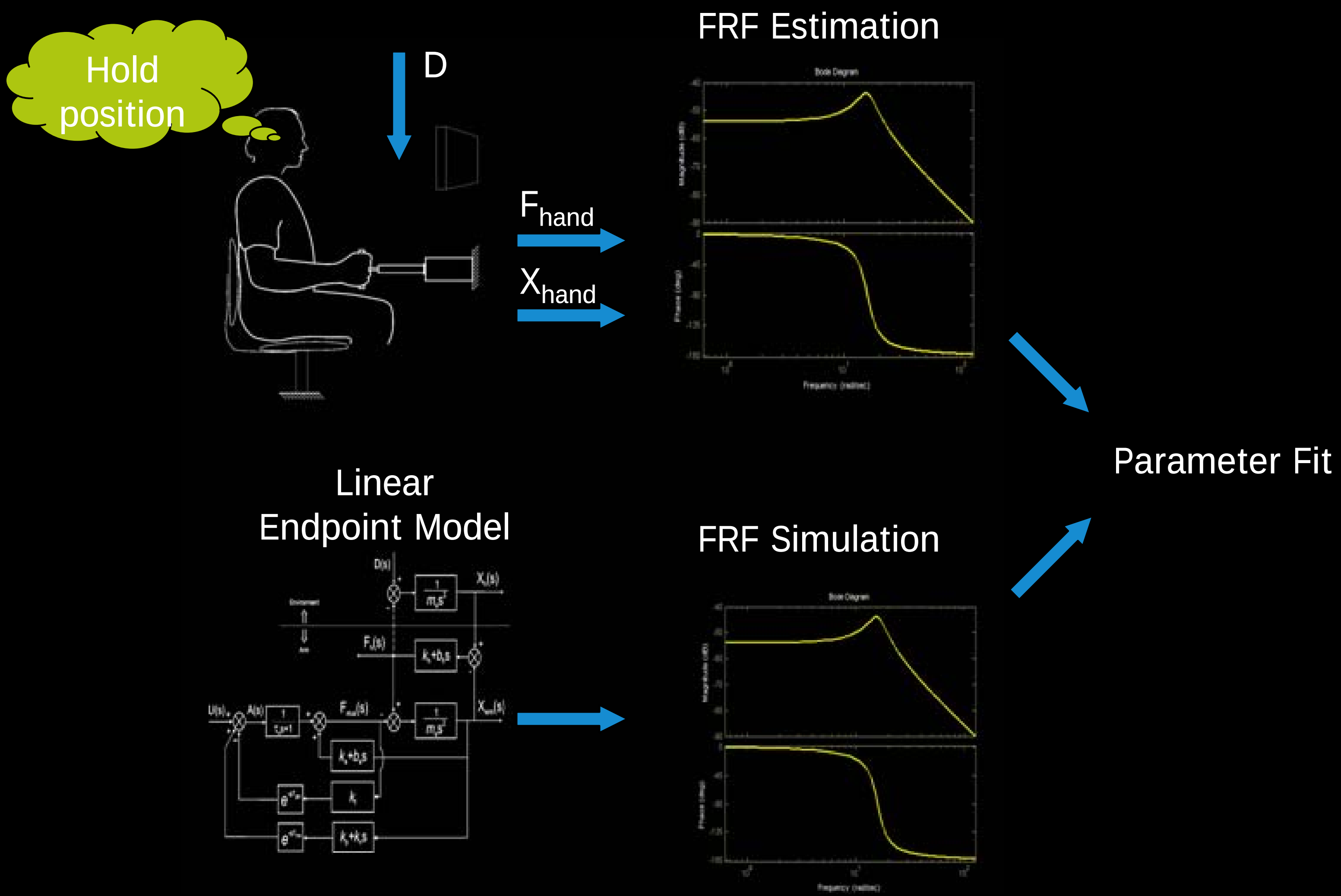


SI Results: Frequency Response Functions

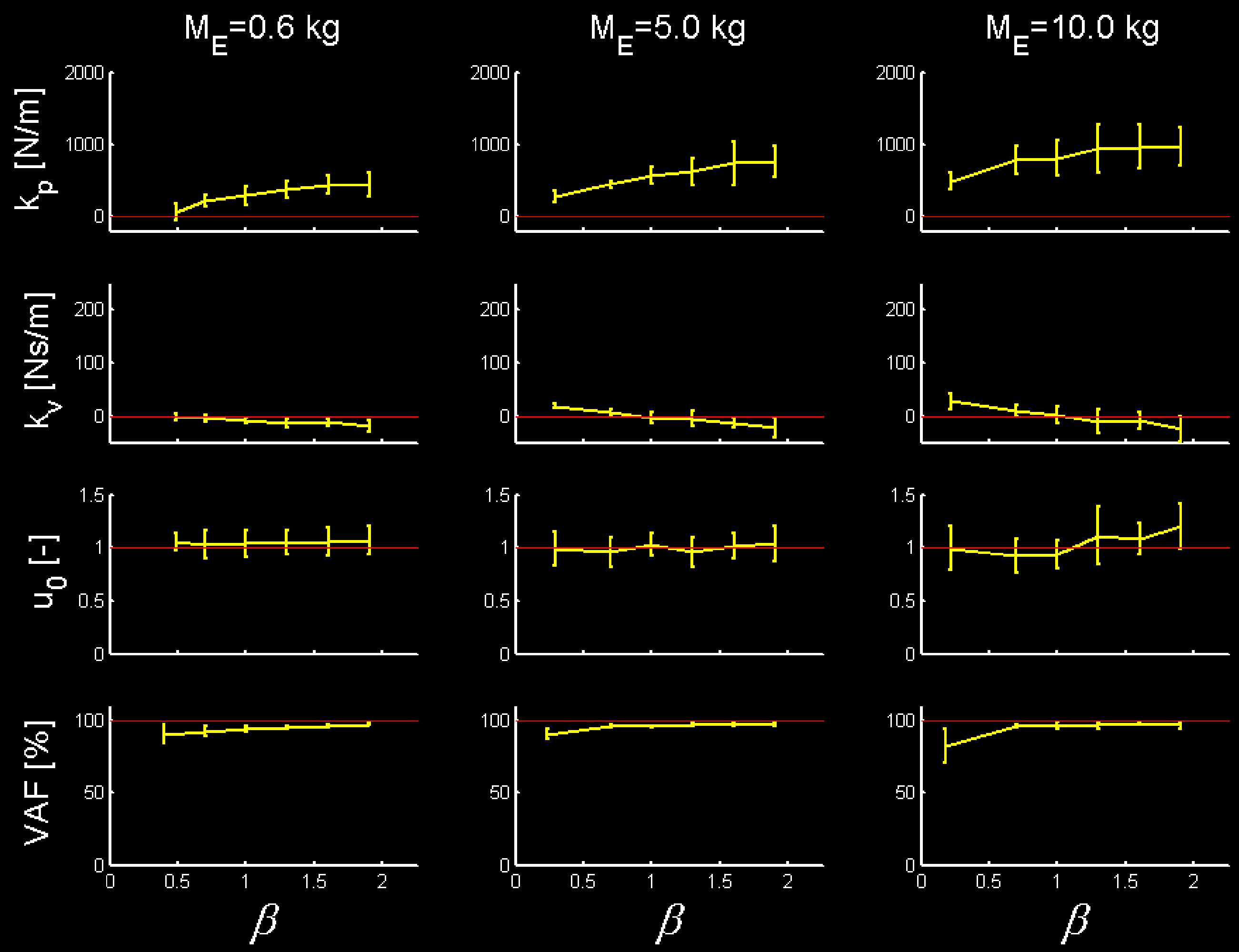
damper off
damper on



Parameter Estimation (PE)

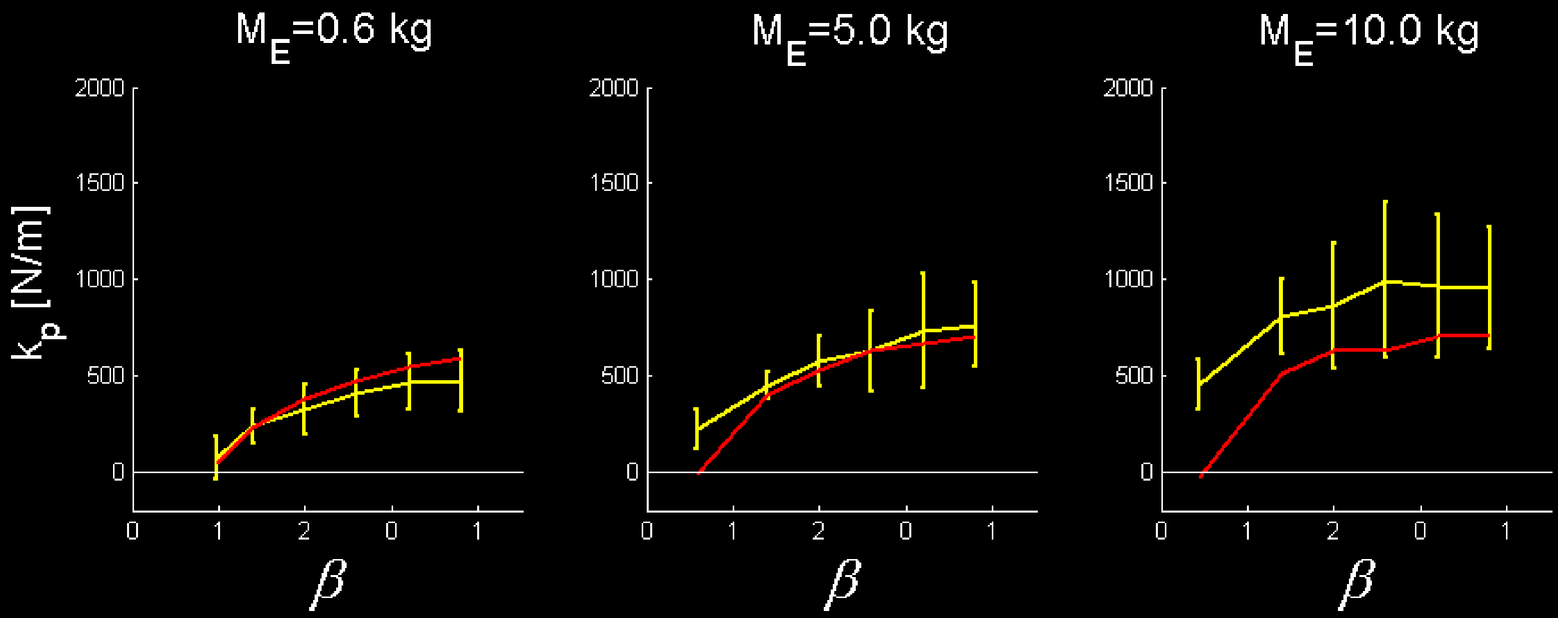


PE Results: stretch reflex estimates

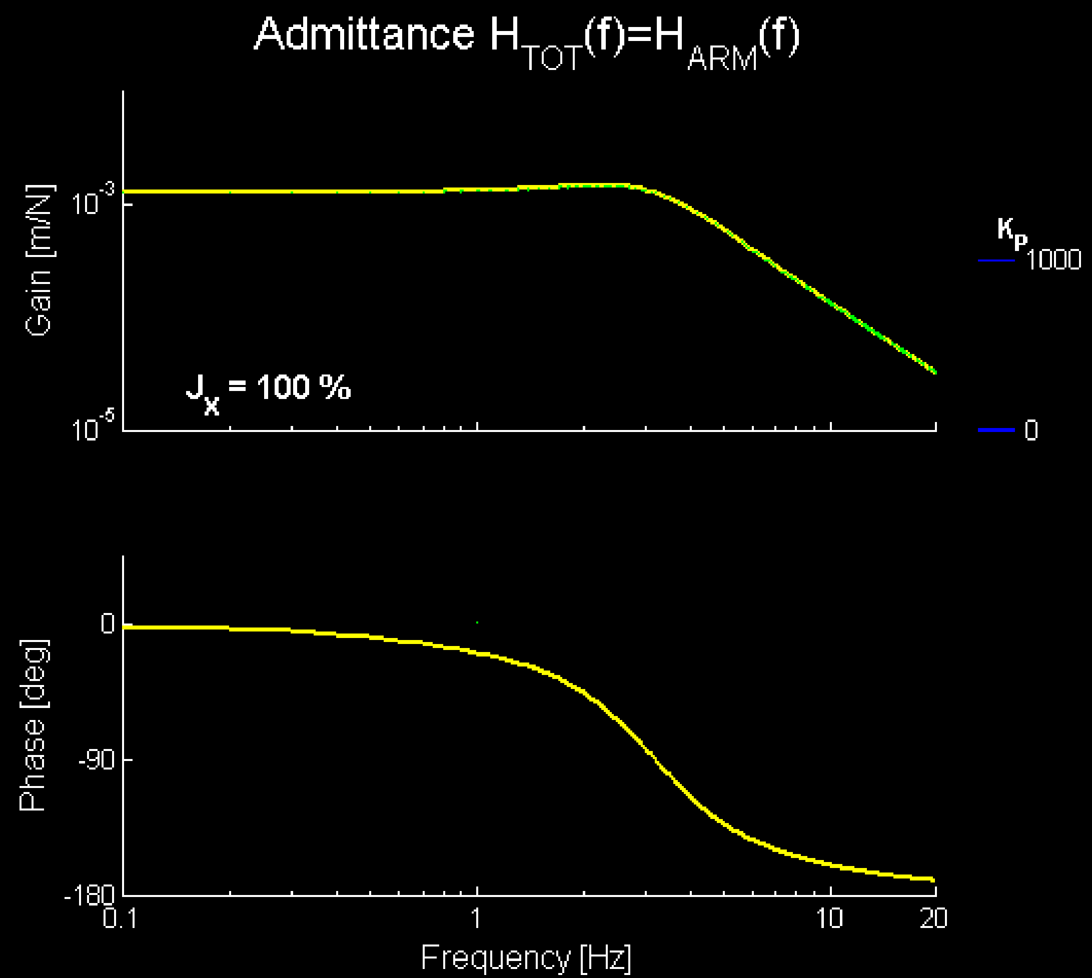


De Vlugt et al. 2002

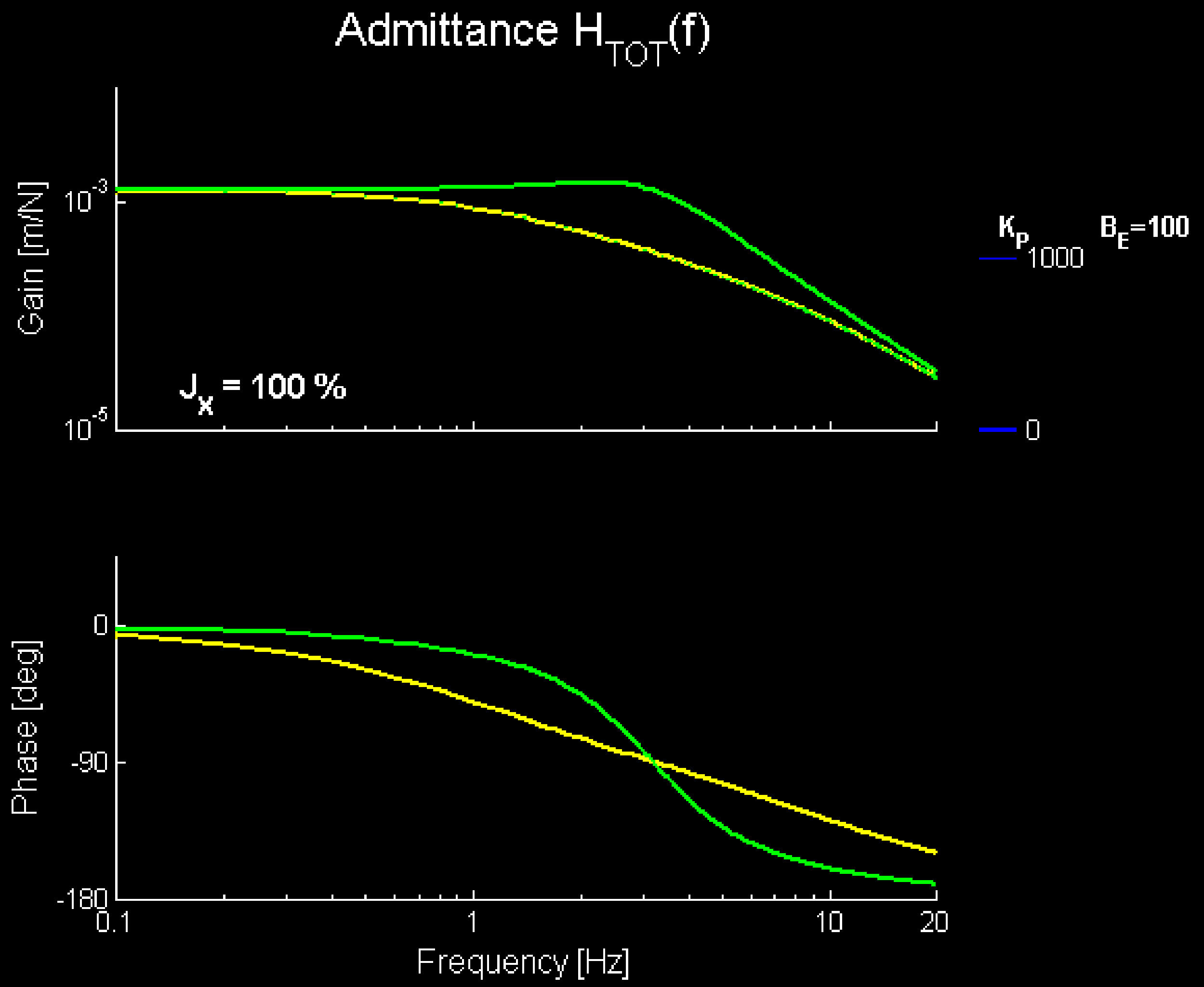
Results: optimized stretch reflex



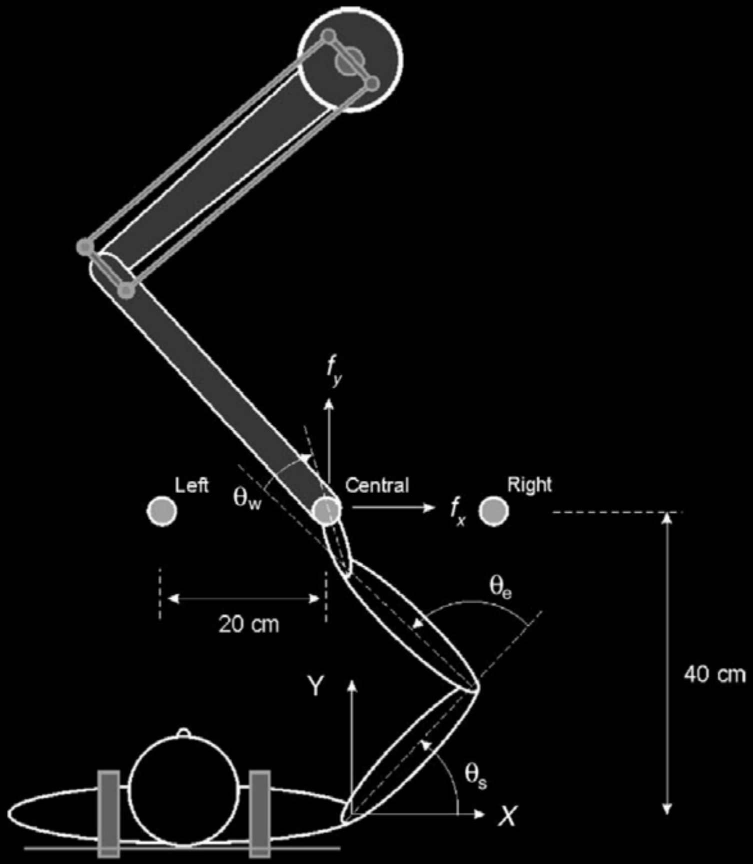
Reflexive Admittance Control: no environment



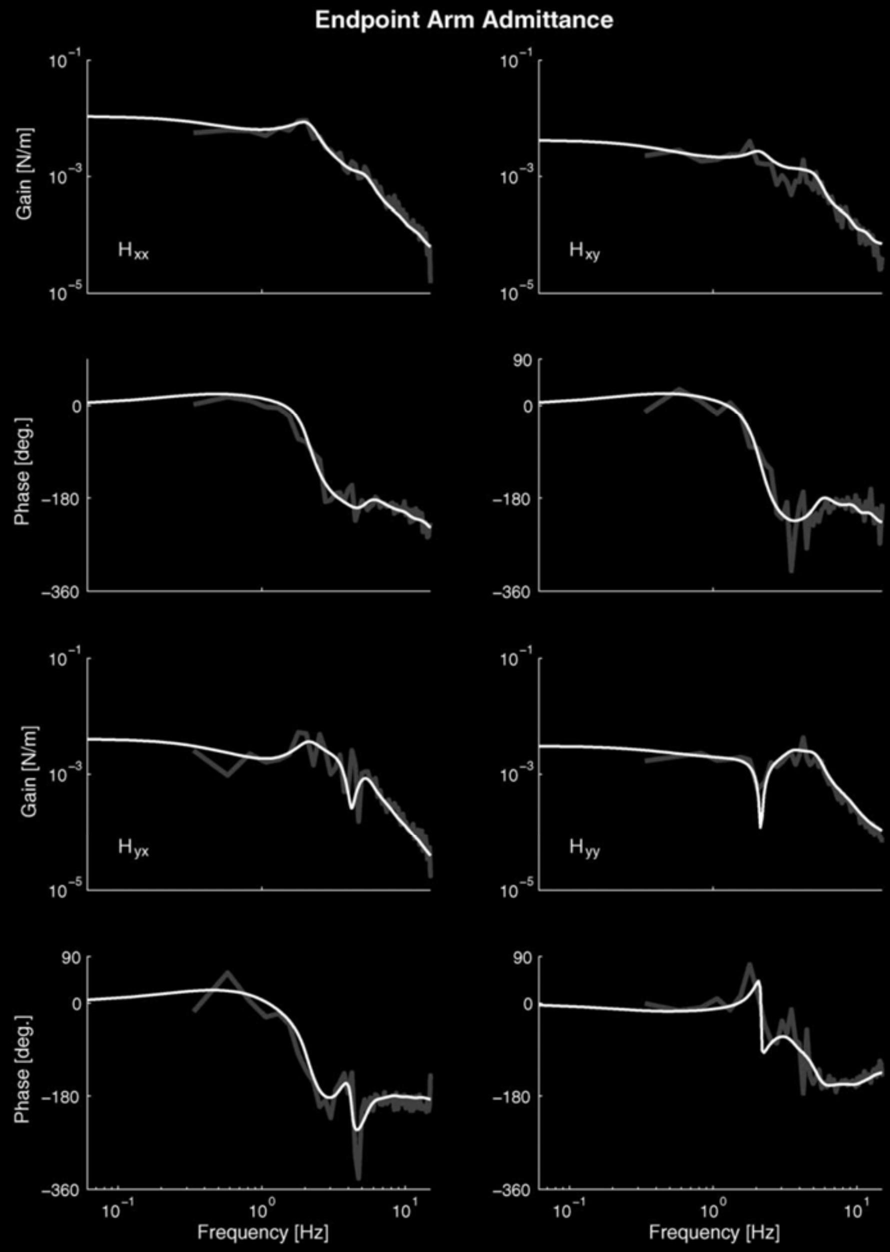
Reflexive Admittance Control: with External Damper



Case 2: SIPE in the 3DOF Shoulder



2DOF FRFs



data
model

PE Result: intrinsic parameters

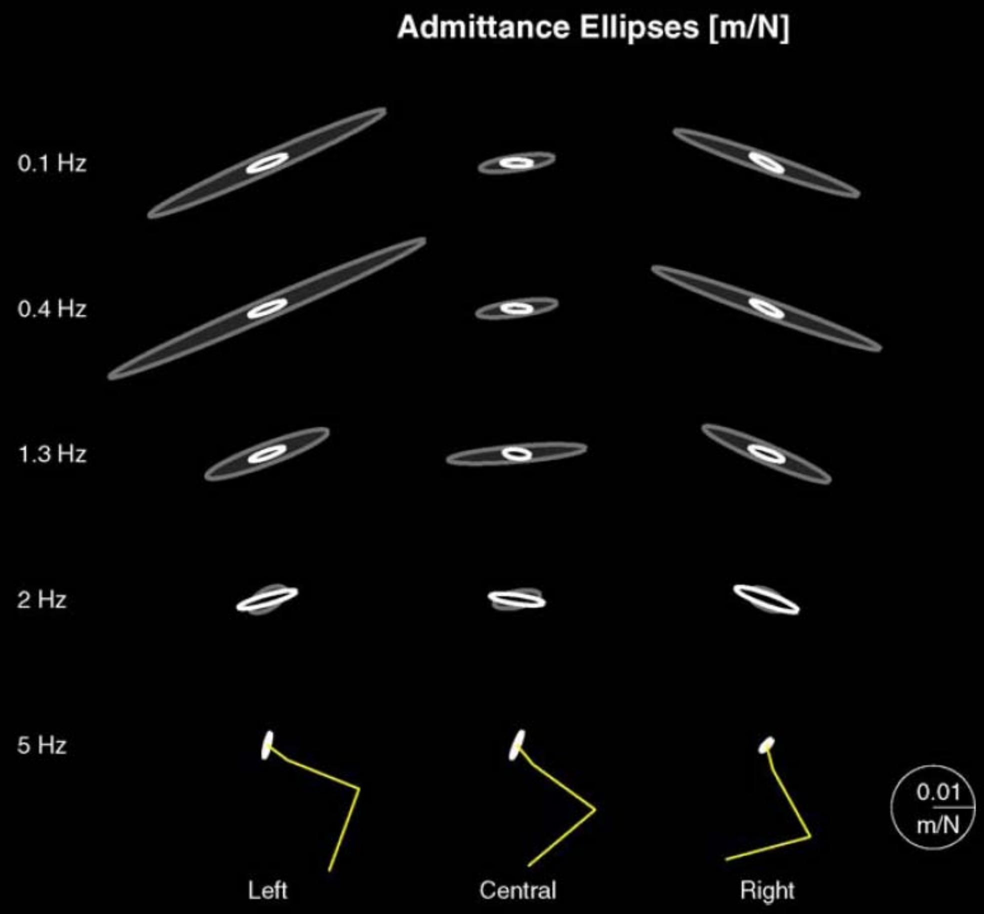
Table 4
Estimated 'invariant' model parameters (mean (S.D.)) for all subjects: segmental mass (m_{hume}, m_{fore}, m_{hand}), hand grip visco-elasticity (B_h, K_h), neural time delay (T_{ds}, T_{de}, T_{dw}) and activation cut-off frequency ($f_{act,s}$, $f_{act,e}$, $f_{act,w}$)

Parameter	Value (mean (S.D.))				
	1[a]	2[a]	3[a]	4[a]	5[a]
m_{hume} [kg]	1.96 (0.295)	1.88 (0.397)	1.78 (0.262)	1.86 (0.388)	2.17 (0.332)
m_{fore} [kg]	1.13 (0.240)	1.19 (0.154)	1.08 (0.148)	1.27 (0.171)	1.18 (0.171)
m_{hand} [kg]	0.496 (0.0976)	0.363 (0.0628)	0.425 (0.0885)	0.546 (0.0483)	0.384 (0.0483)
B_h [N s/m]	167 (74.9)	184 (66.1)	194 (101)	167 (109)	214 (109)
K_h [kN/m]	7.39 (3.09)	6.46 (2.03)	8.06 (2.53)	13.3 (4.27)	8.28 (4.47)
T_{ds} [ms]	30.4 (2.48)	29.4 (3.17)	29.7 (3.51)	30.7 (3.17)	29.7 (3.51)
T_{de} [ms]	33.4 (2.61)	32.7 (2.89)	34.1 (2.80)	33.4 (2.61)	32.0 (1.80)
T_{dw} [ms]	40.4 (3.00)	37.7 (1.89)	37.6 (1.54)	41.4 (2.13)	39.8 (2.68)
$f_{act,s}$ [Hz]	1.98 (0.0842)	2.11 (0.139)	2.08 (0.145)	1.99 (0.164)	2.08 (0.145)
$f_{act,e}$ [Hz]	2.26 (0.136)	2.35 (0 (0.101)	2.28 (0.107)	2.35 (0.107)	2.26 (0.136)
$f_{act,w}$ [Hz]	2.11 (0.175)	2.21 (0.132)	2.09 (0.171)	2.13 (0.147)	2.09 (0.132)

[a] Subject.

De Vlugt et al. 2006

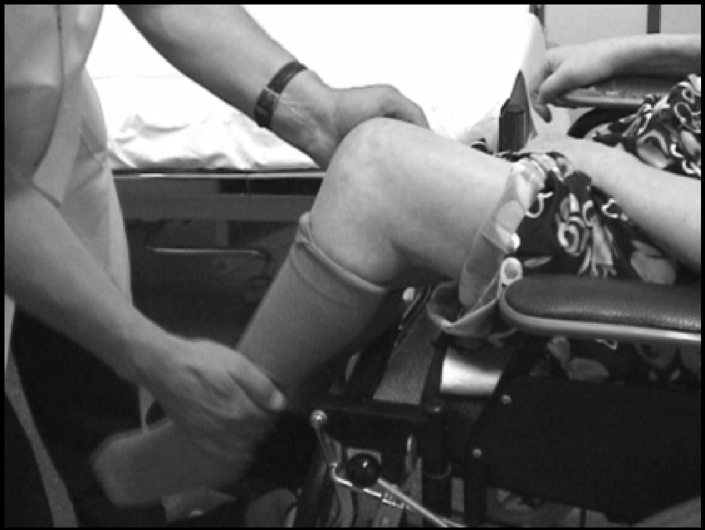
Stiffness Ellipses



data
model

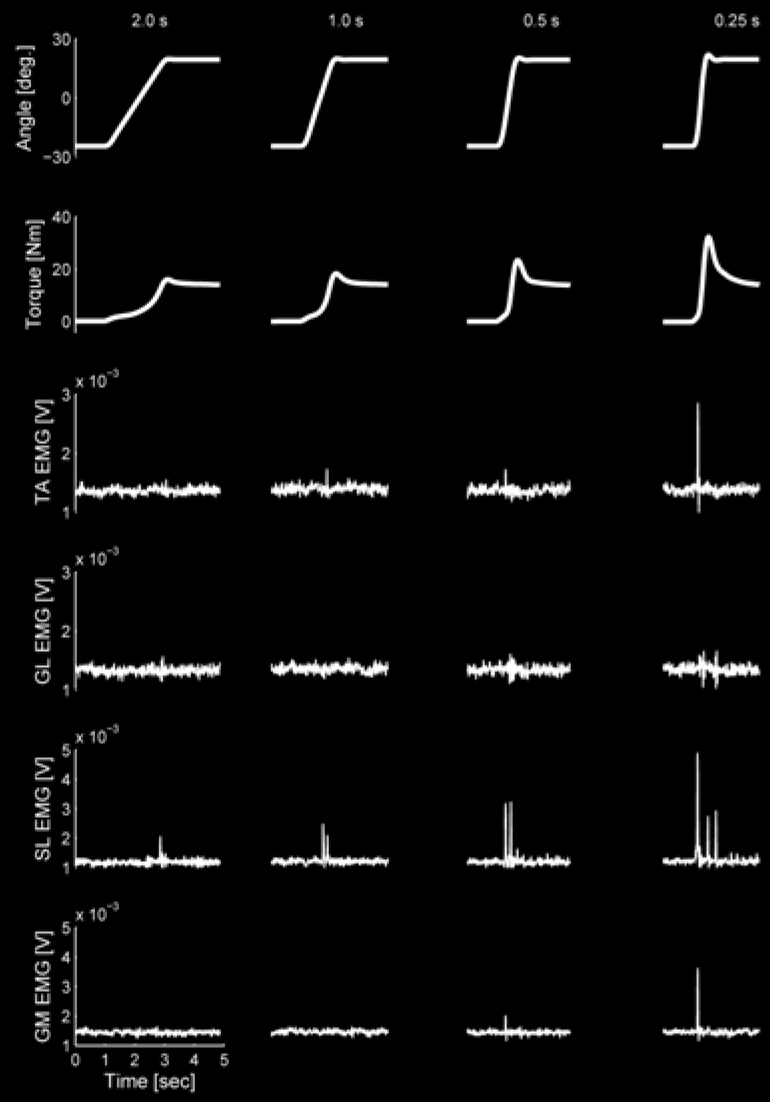
reflexes turned of / turned on

Case 3: Nonlinear case: Ramp-hold Ankle rotation in stroke



De Vlugt et al. 2010

Nonlinear case: Ramp-hold Ankle rotation

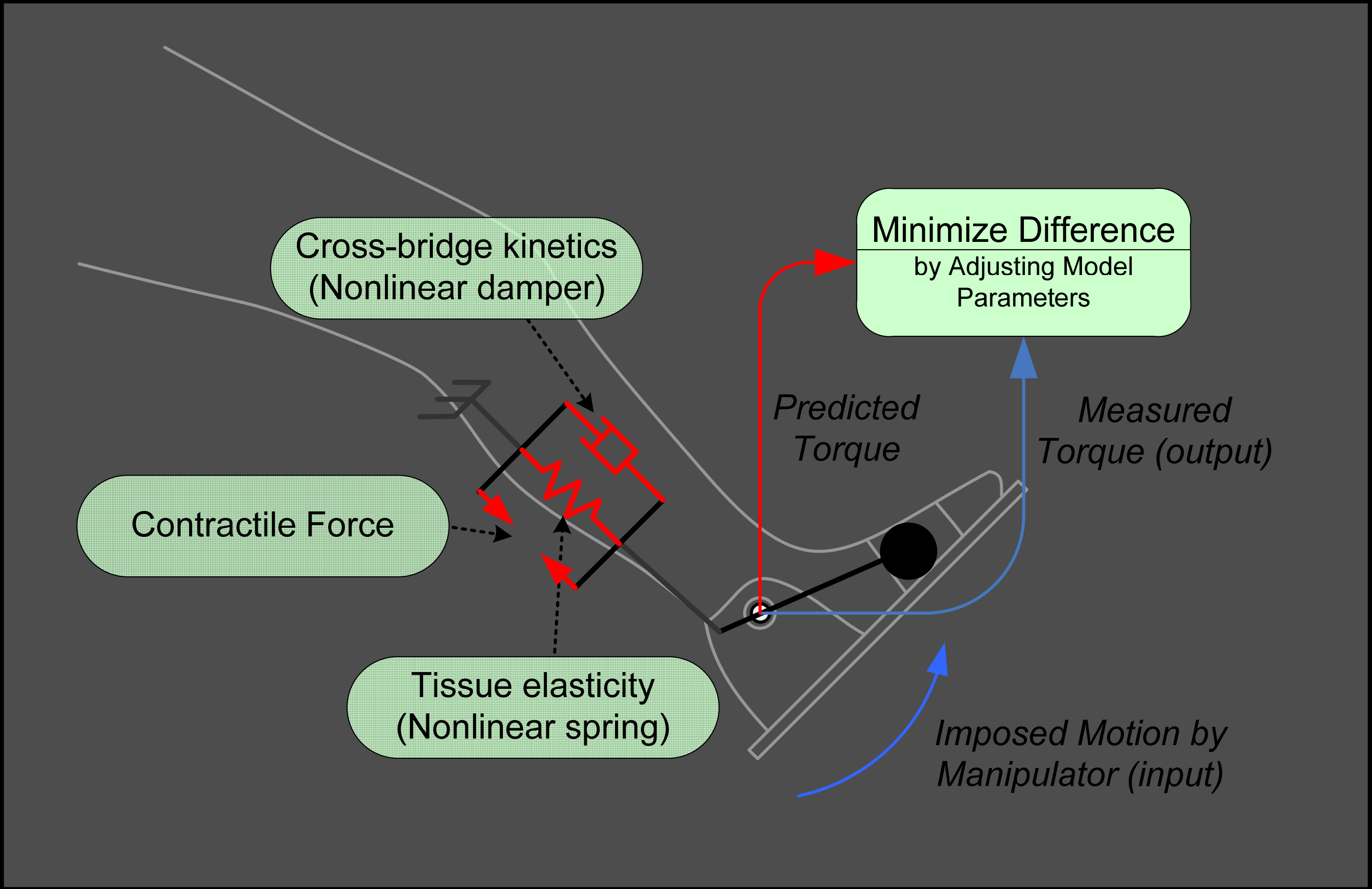


- stroke (n = 19)

Goal:

- estimate passive visco-elasticity and stretch reflex dynamics and compare to Ashworth Scale

Direct Physical Parameterization

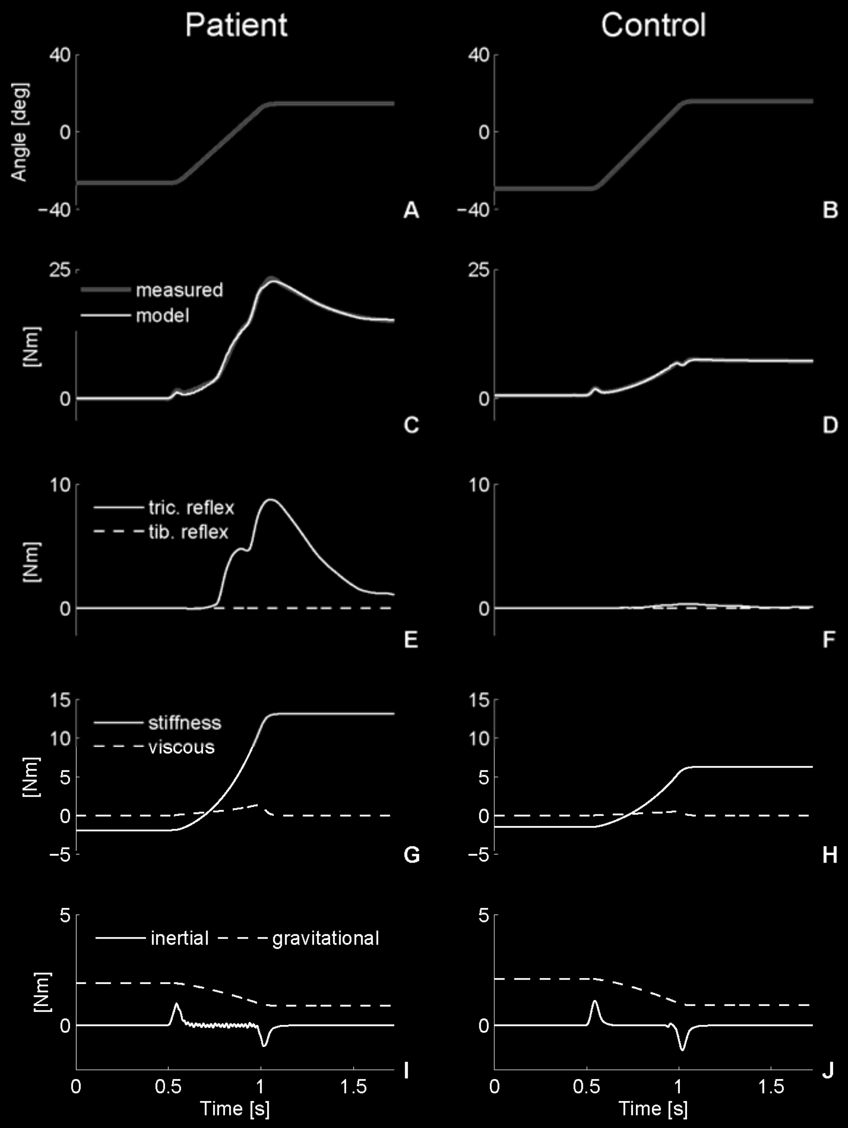


No Identification, Direct Parameterization

direct parameterization of a nonlinear model in time domain

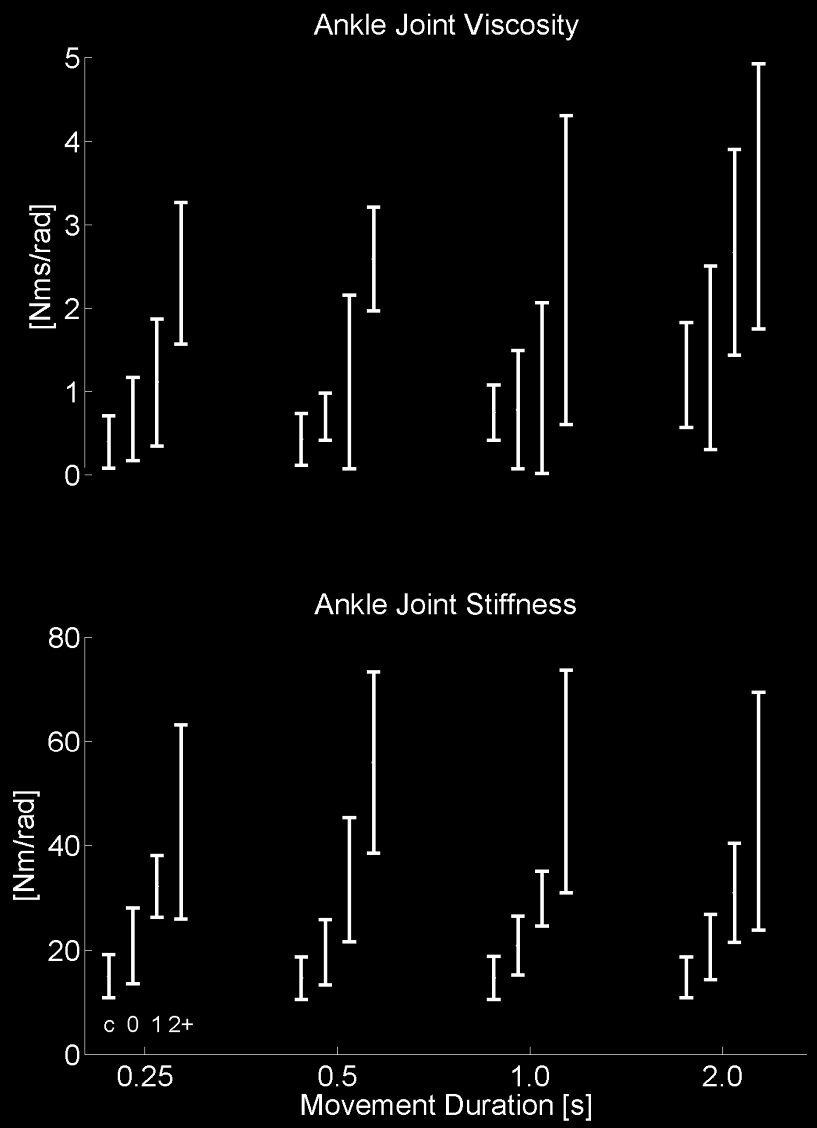
Parameters:

- inertia
- tissue viscosity
- tissue elasticity
- activation dynamics
- contractile dynamics



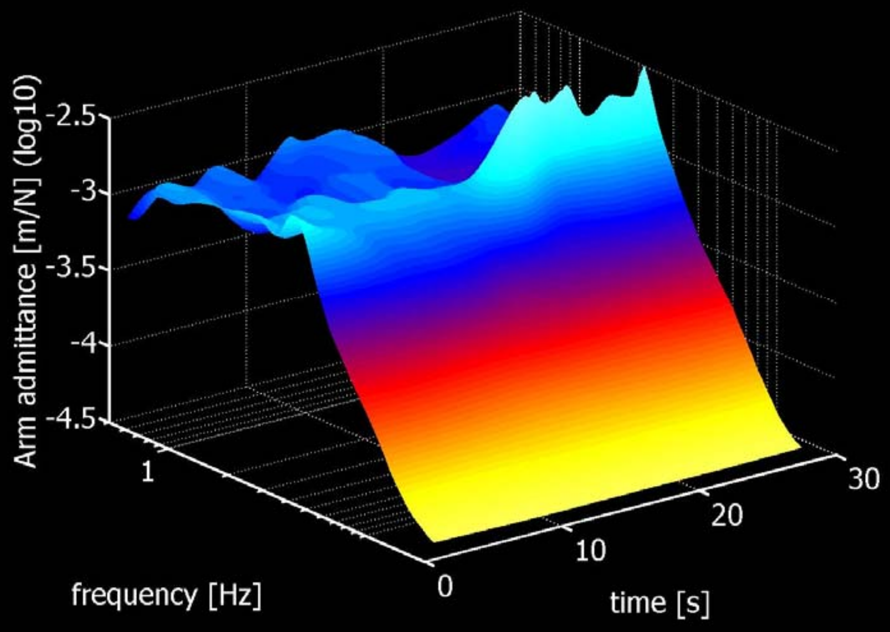
Main Result

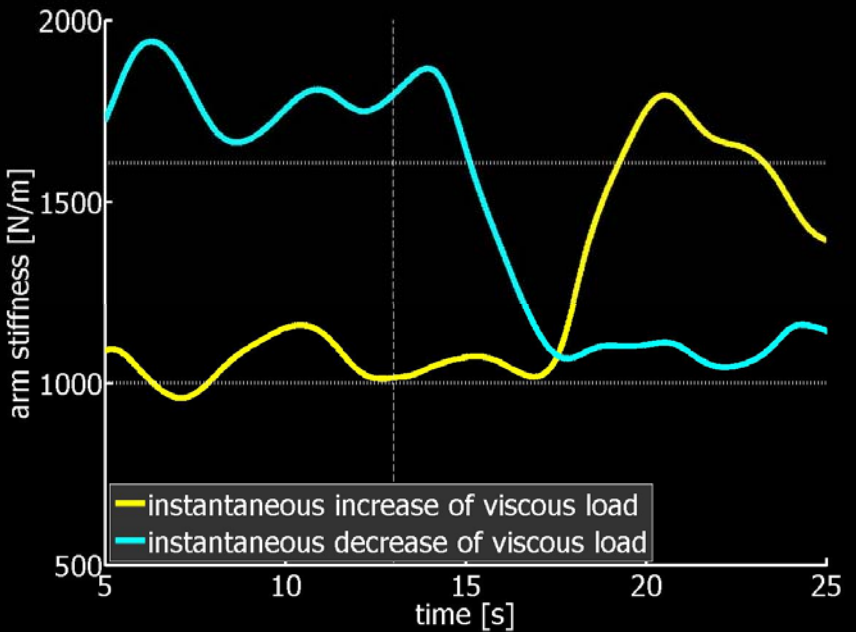
- Detailed parameterization possible:
  - Accurate (VAF > 90%)
  - Valid (low parameter SEM)
- Viscosity decreased with movement velocity
- Passive stiffness correlated to Ashworth Scale



Challenges: SIPE during movement

- Time Varying Joint Admittance
  - Wavelets and subspace techniques
  - Collaboration between the fac. of 3ME (DCSC, BMechE) and Aerospace Eng.





Summary

- Linear behavior: frequency domain can be used and provides direct qualitative information about the human joint dynamics.
- Nonlinear behavior: time domain analysis by direct parameterization of a physical nonlinear model of the human joint.
- Towards Time Varying System Identification....

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Graduate Student Master Projects

- Master Projects at NMC Lab involves a mixture of SIPE, physiology and clinical issues
- Many (international) opportunities for Graduate Students
  - internship (stage), preferably outside the Netherlands
  - fundamental projects: TUD
  - clinical projects: LUMC, Erasmus MC, VUMC