Stiffness - muscle models

Alistair Vardy (TUD)   STIFF Summer School 2011
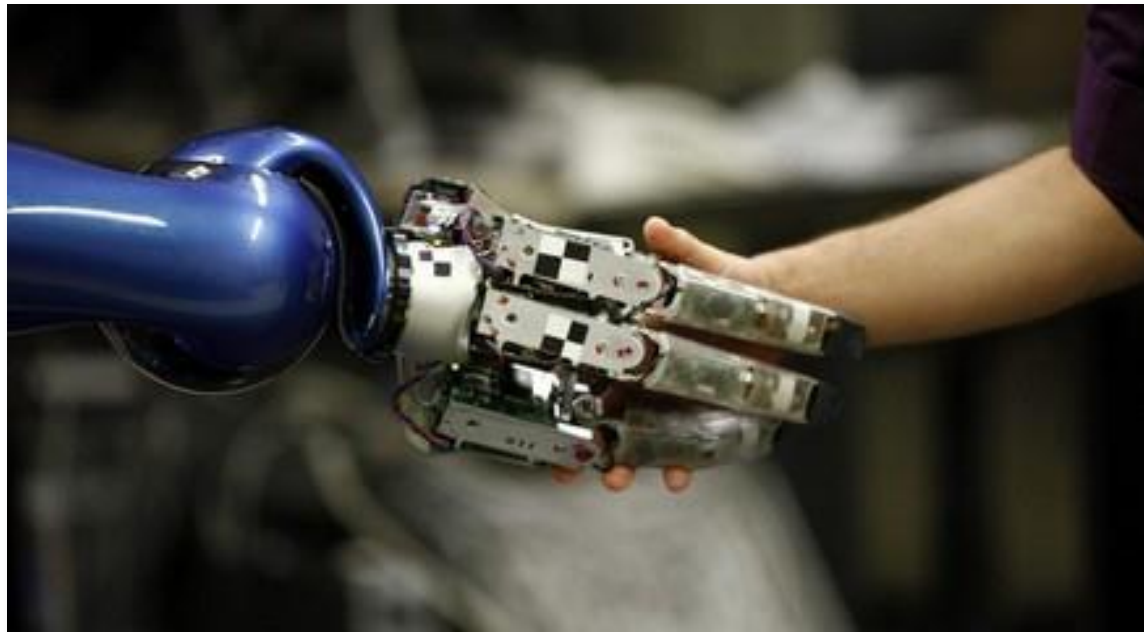
Delft – STIFF (1)

Delft – STIFF (2)

- Control

- System identification

- Linear Parameter Varying identification

- Musculoskeletal modeling

Variable impedance

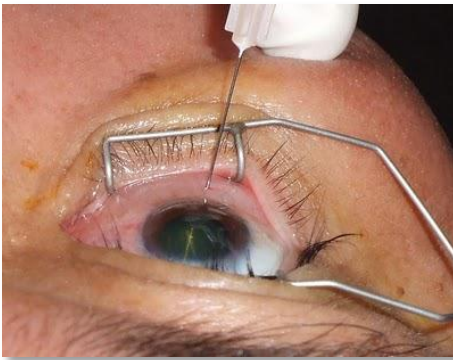# Human robot interaction

Human robot interaction

Human behavior

Stiff ⟵⟶ Flexible

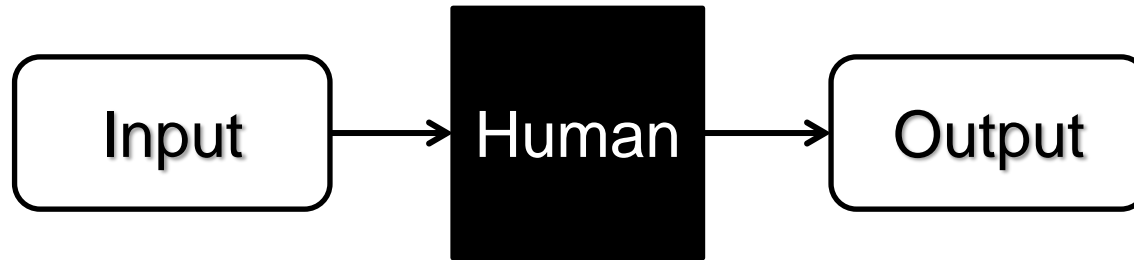# Human stiffness

How do we measure human stiffness?

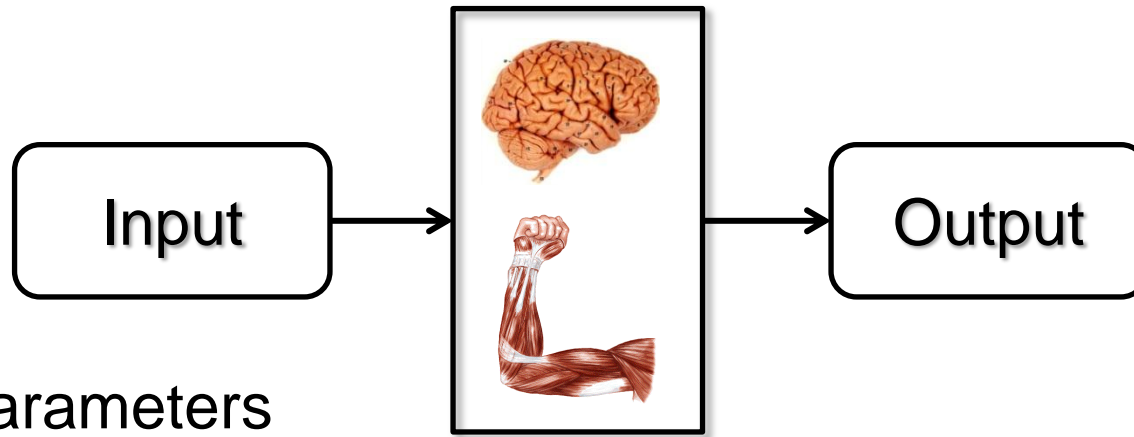*Where does human stiffness come from?*

How do we model stiffness?

Measuring human stiffness

Input → Human → Output
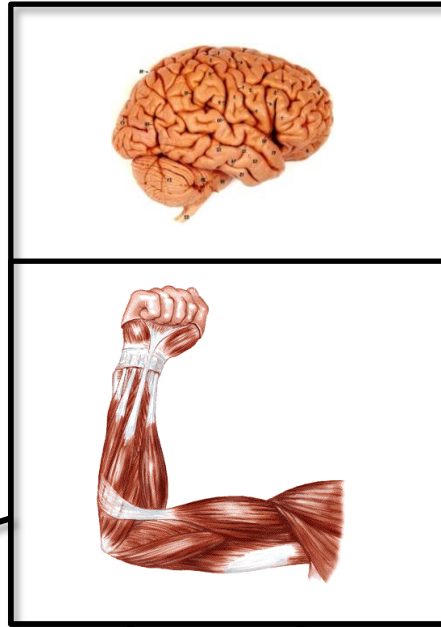
$$Z(\omega) = \frac{F(\omega)}{v(\omega)}$$

Input → → Output

Model parameters

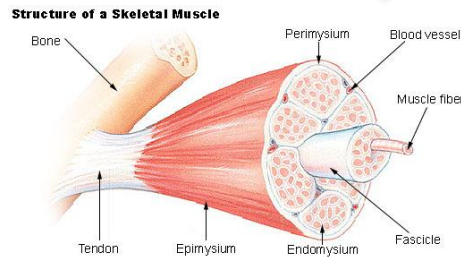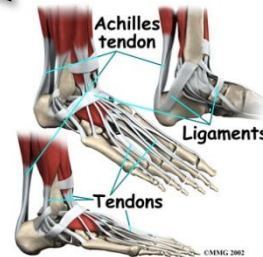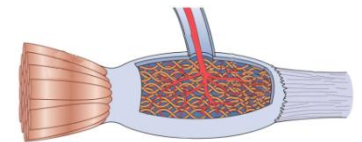# Human stiffness

Controller

Musculoskeletal system

Skeleton   Muscles   Ligaments   Sensors

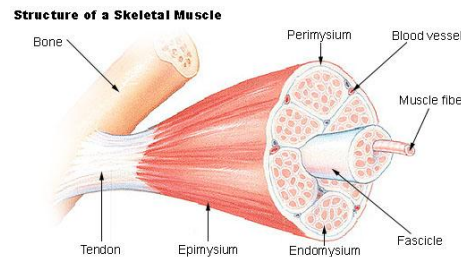# **Human**

Musculoskeletal stiffness comes from:

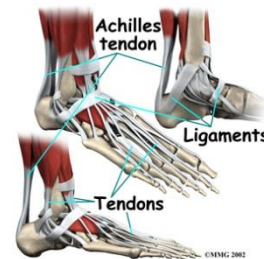- Ligaments
- Muscles
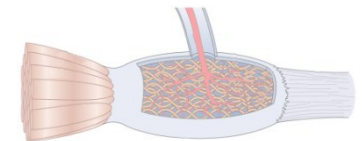- Connective tissue

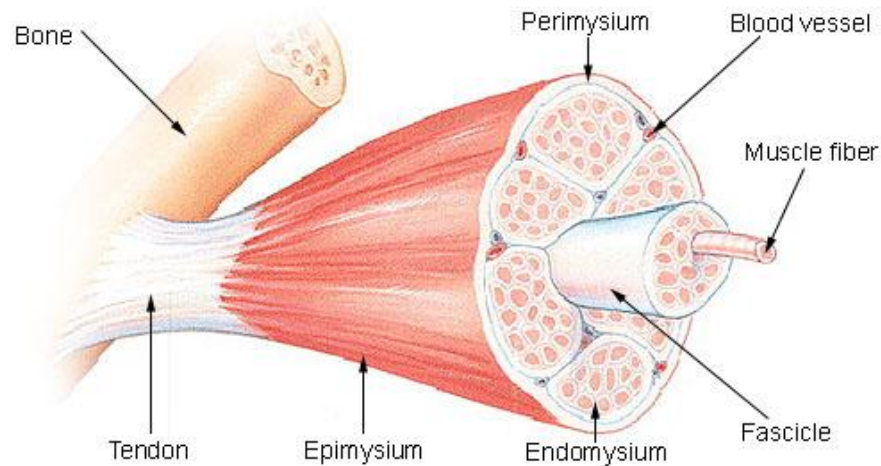Skeleton   Muscles   Ligaments   Sensors

Human (model)

Variable stiffness comes from:
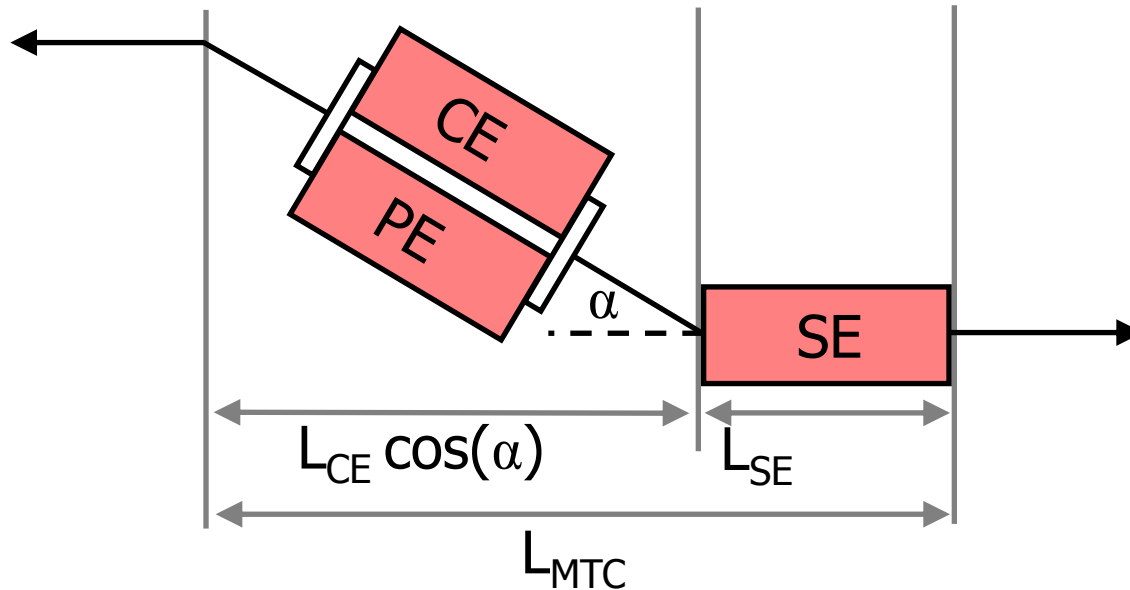
Structure of a Skeletal Muscle
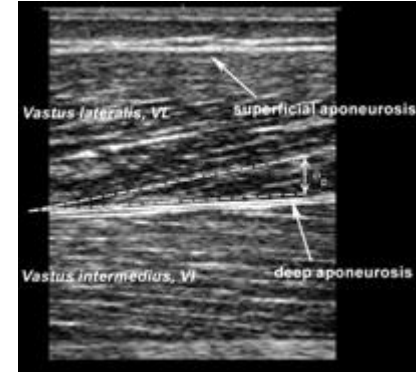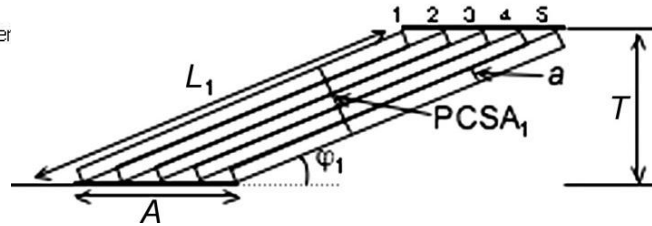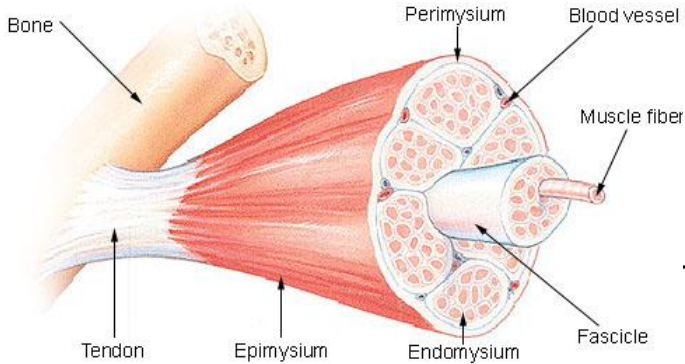

Muscles

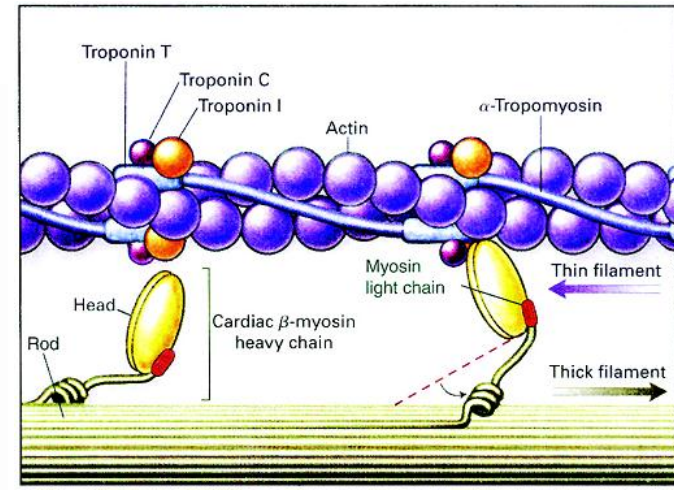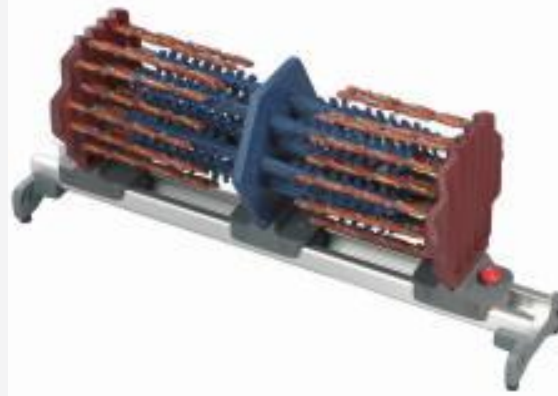# Muscle, global properties

Structure of a Skeletal Muscle
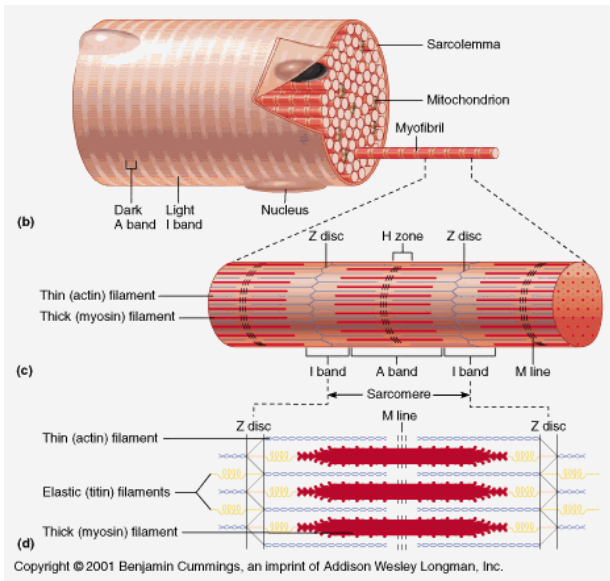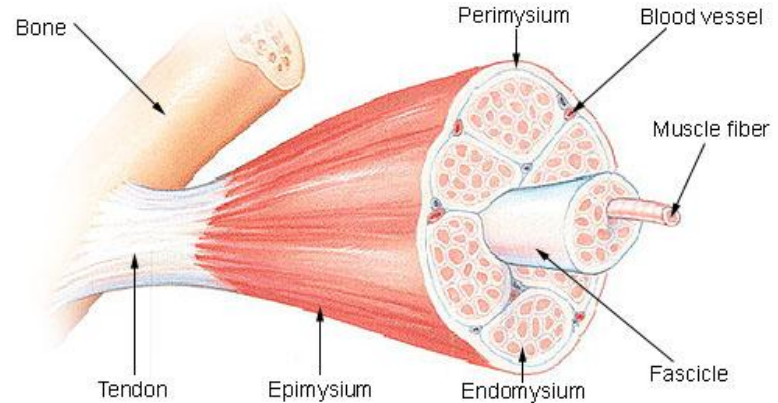
$$L_{CE}\cos(\alpha) \qquad L_{SE}$$

$$L_{MTC}$$

Muscle, contractile element
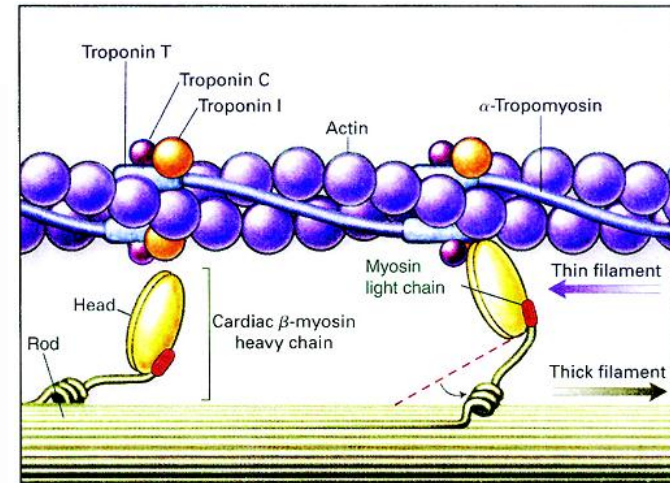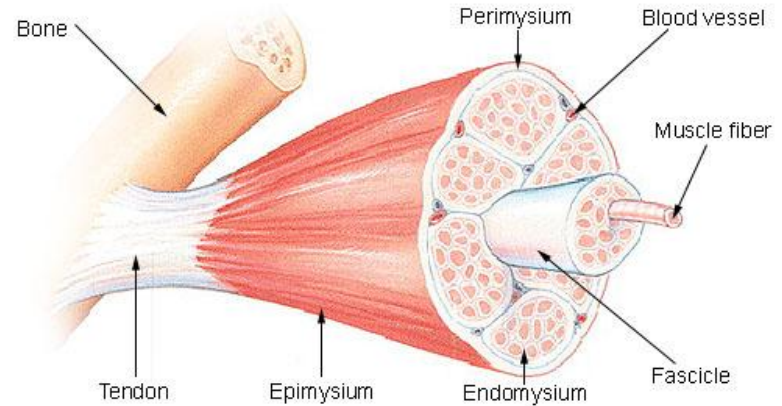
Cross-bridge cycling
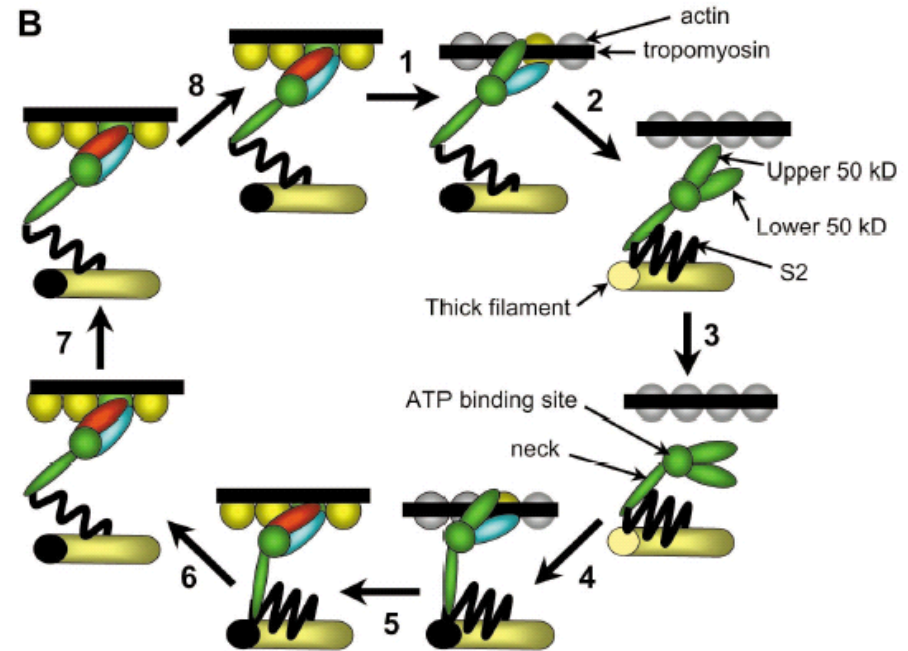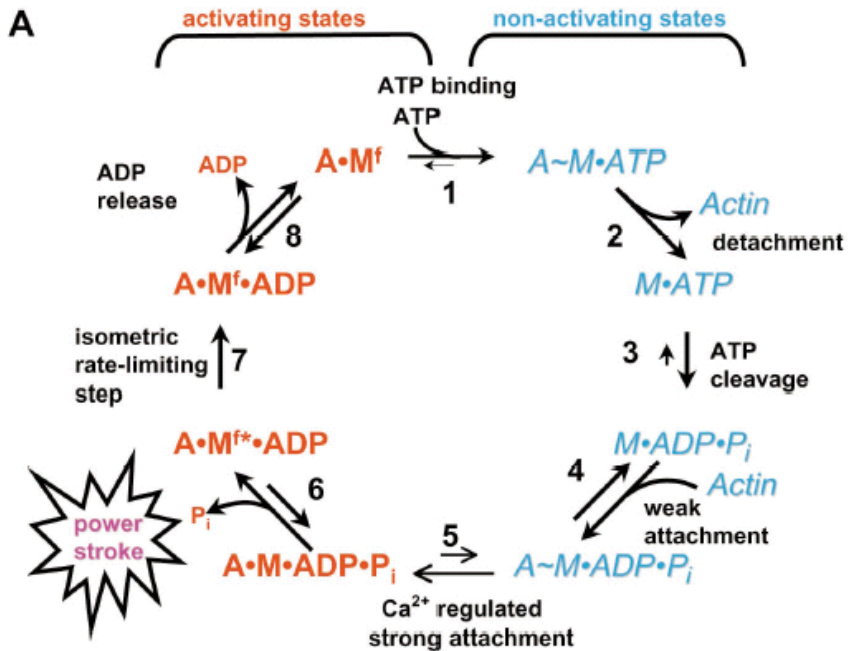
Too much information?

- Research question

- Accuracy

- Type of movement

Model and detail

Structure of a Skeletal Muscle
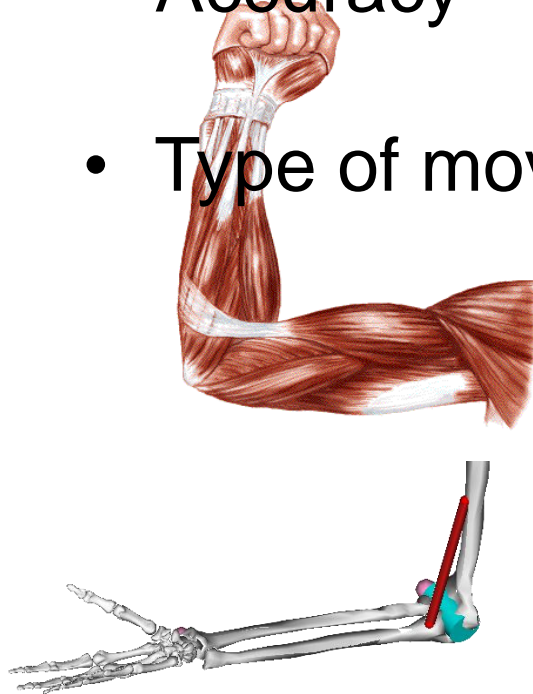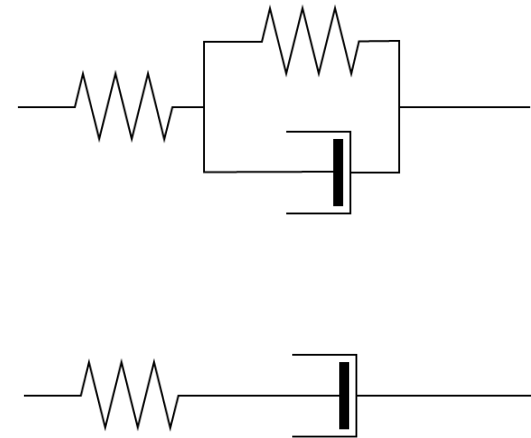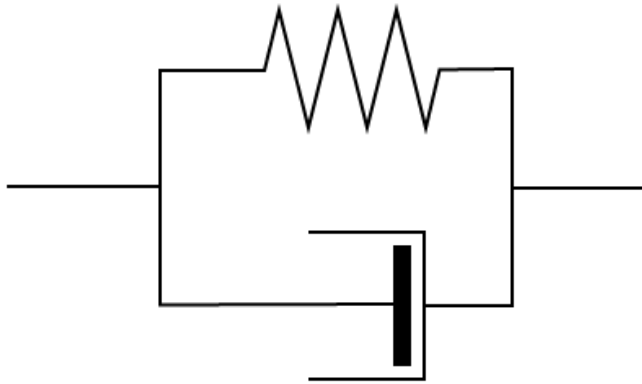
How much do we need?

- Research question

- Accuracy

- Type of movement
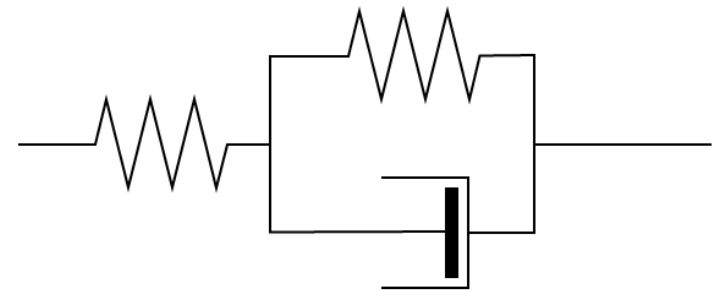
Simple muscle models

Mass spring damper

- Three parameters (M,B,K)
- Can give good representation of behavior
- Physiologically inaccurate
- Poor interpretation of human stiffness

Hill muscle model

Hill model (1938)

- Based on experimental findings
- Parameters known from literature
- Fast, easy to implement
- Standard model in OpenSim, Anybody, Madymo
- Less accurate for fast eccentric contractions (impact)
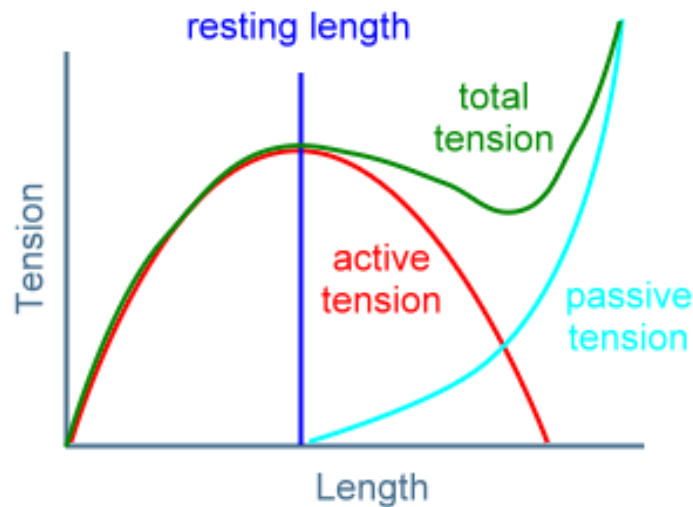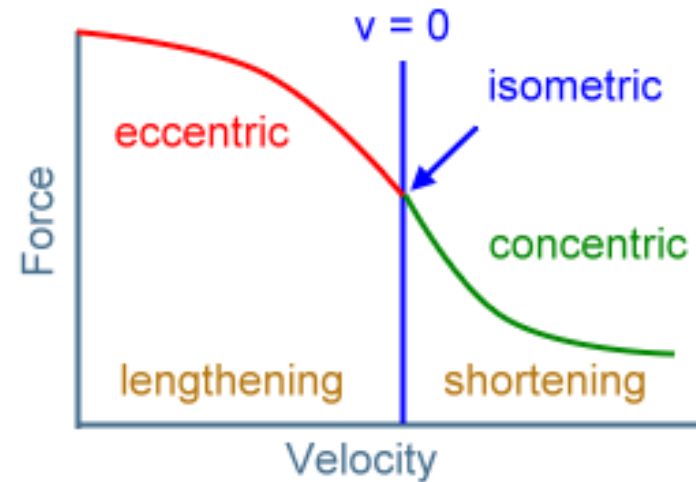- Less accurate stiffness and damping

Hill muscle model

Hill model (1938)

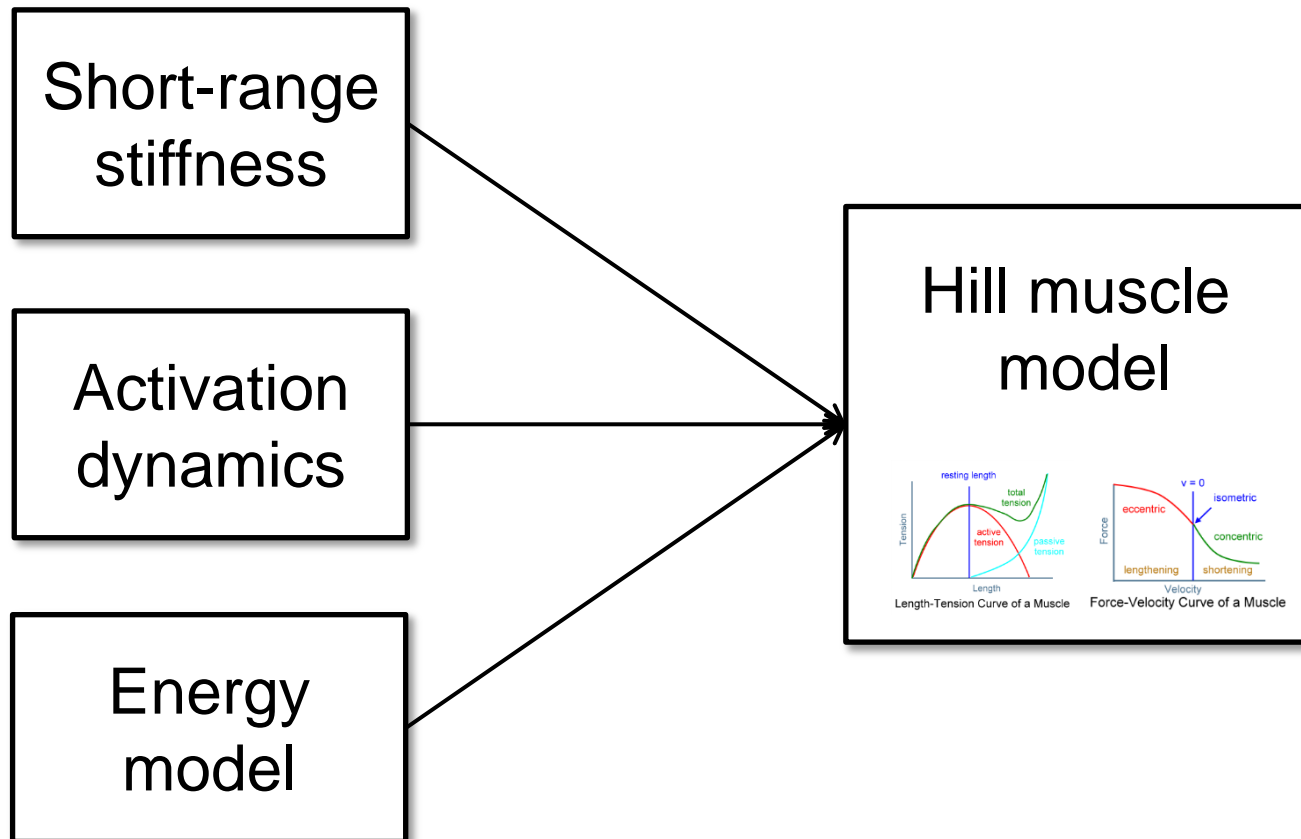Force-length relationship

Force-velocity relationship

Parameters known for a wide range of muscles

Hill muscle model

Hill model (1938)

Short-range stiffness

Activation dynamics

Energy model

Hill muscle model

Hill muscle model

Will always remain a descriptive model

Huxley cross-bridge model

Huxley cross-bridge model (1957)

- Based on cross-bridge dynamics
- Possibly more accurate model
- Physiological interpretation
- No need for add-ons to compensate for behavior
- Binding and unbinding parameters are unknown

Huxley cross-bridge model

– Distribution of cross-bridges for length x and at time t

$$n(x, t)$$

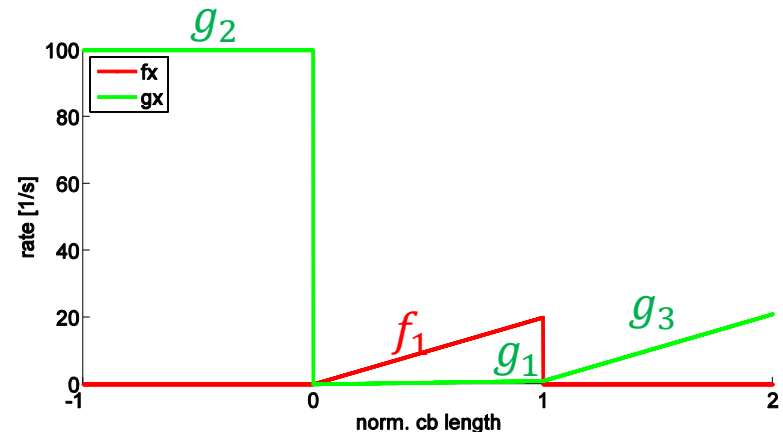– PDE: $\quad n_t - v(t)n_x = f(x) - [f(x) + g(x)]\,n$

– Binding and unbinding rate functions $f(x)$ and $g(x)$
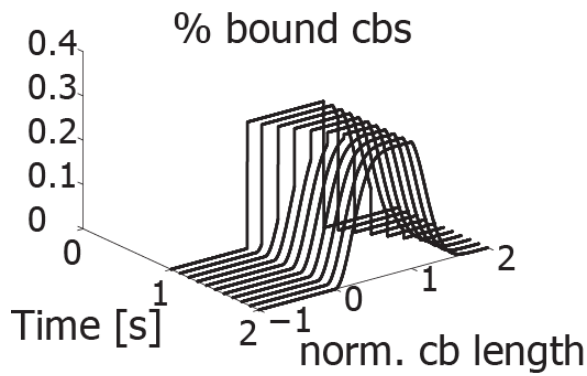
• *Parameters:*

$$f_1$$
$$g_1, g_2, g_3$$

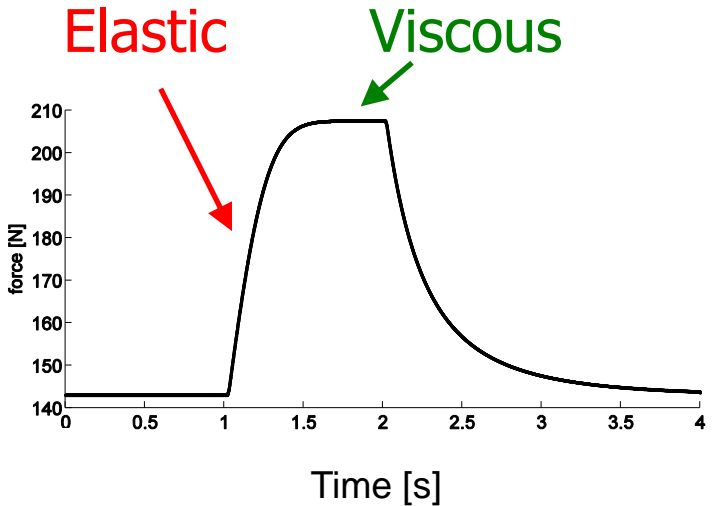– Maximum bond length h

Huxley cross-bridge model

- Short-range stiffness in the Huxley muscle model

Normalized muscle length

Elastic   Viscous
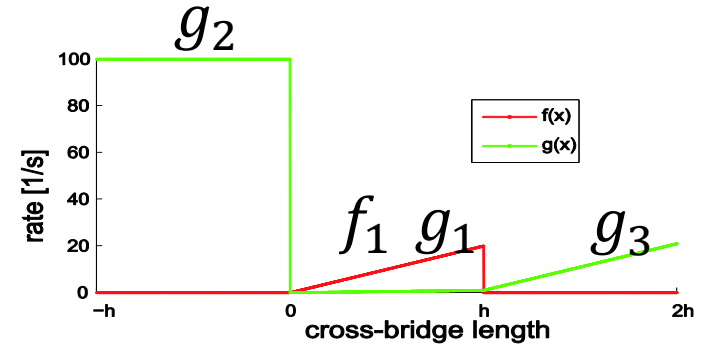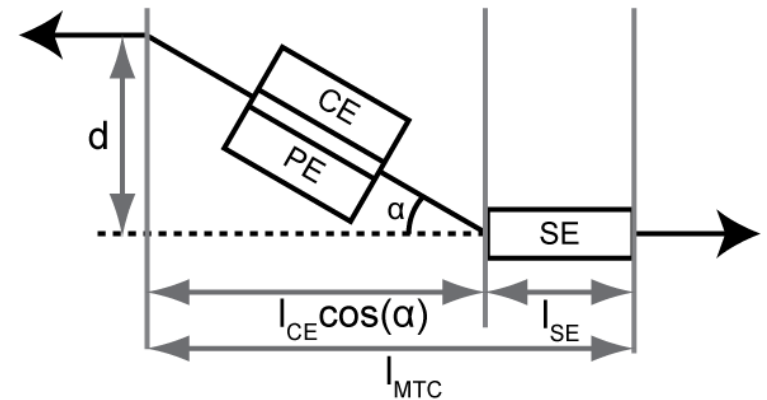
% bound cbs

Time [s]

norm. cb length

Time [s]
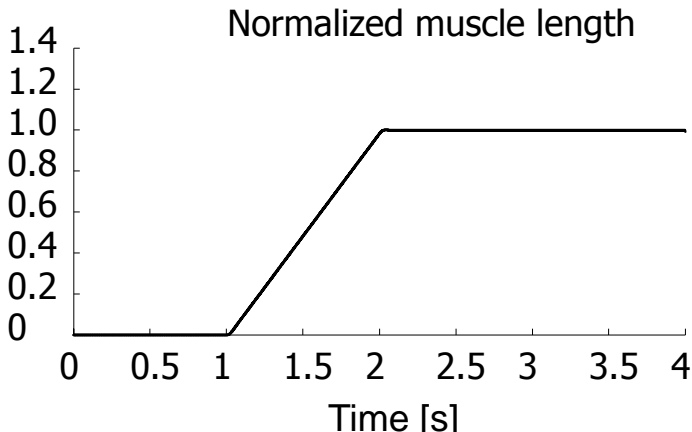
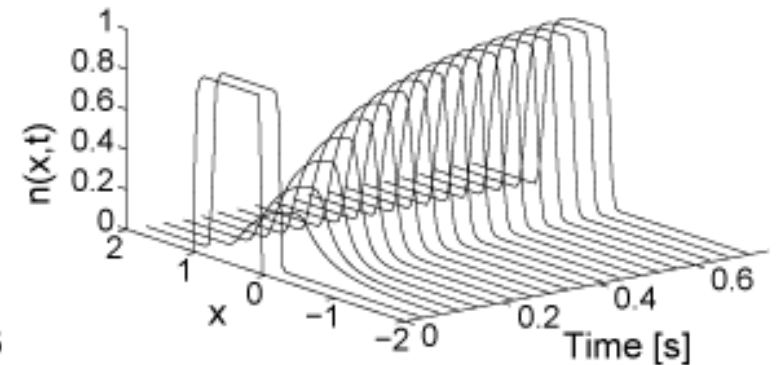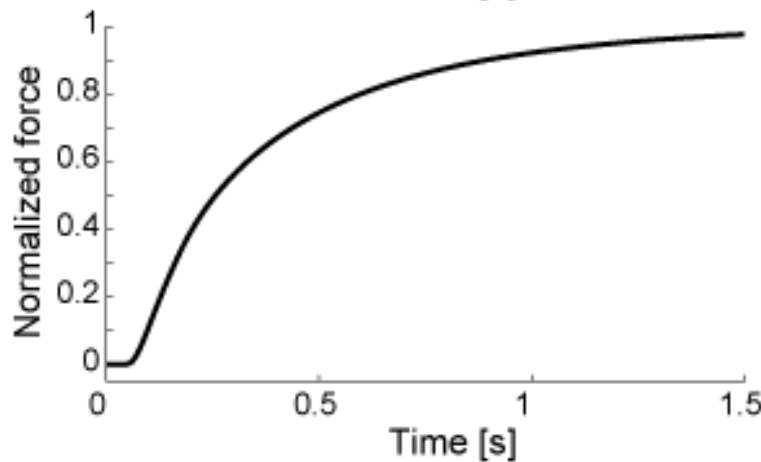# Huxley cross-bridge model

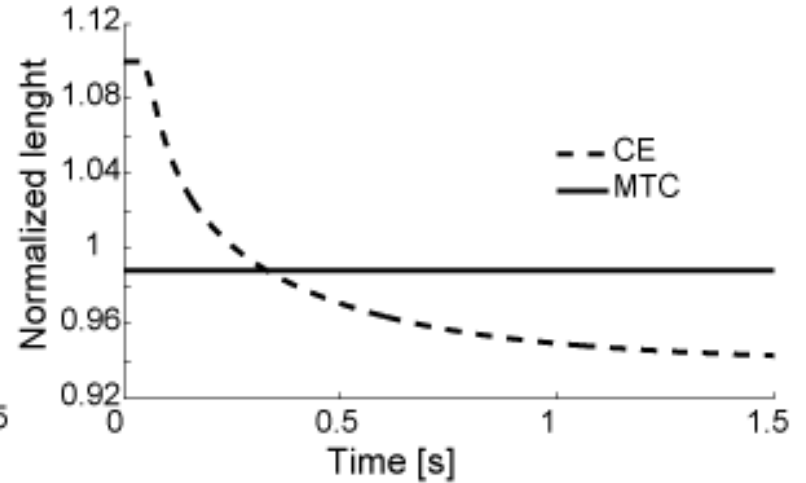- Rate parameters estimated from cats, rats, and frogs

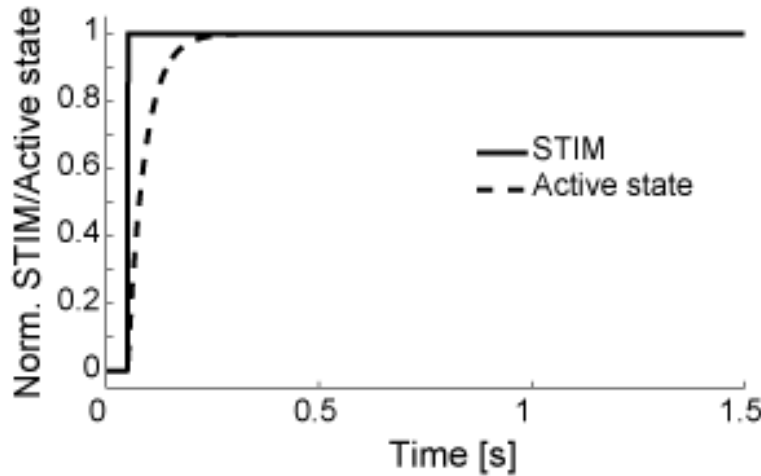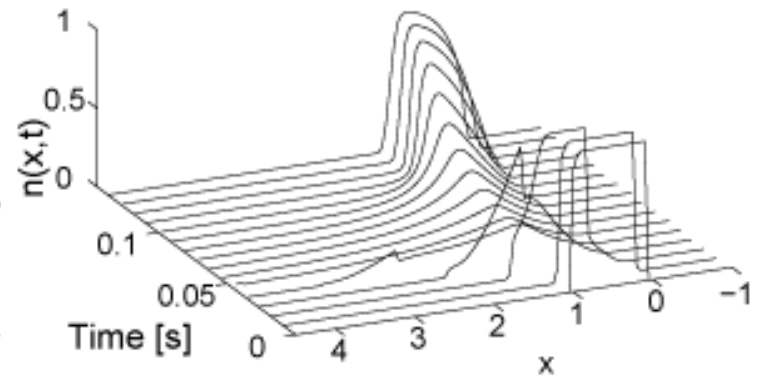

- Need for non-invasive measures

- We need a muscle-tendon model
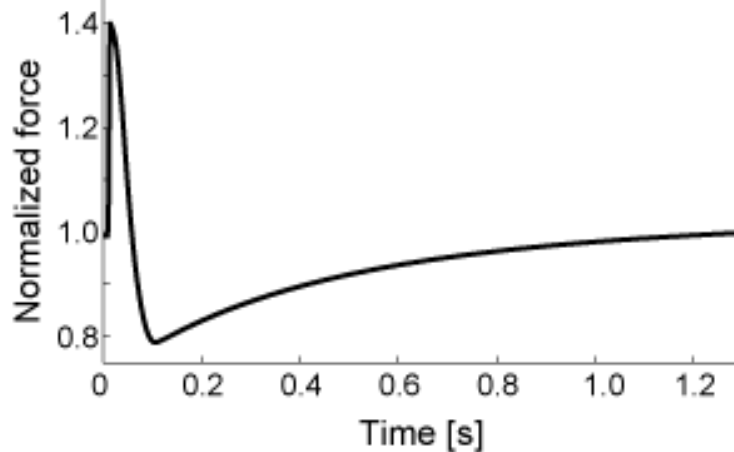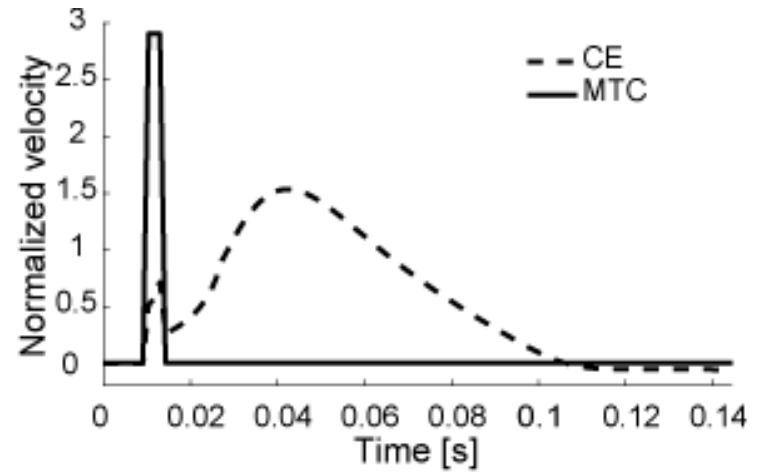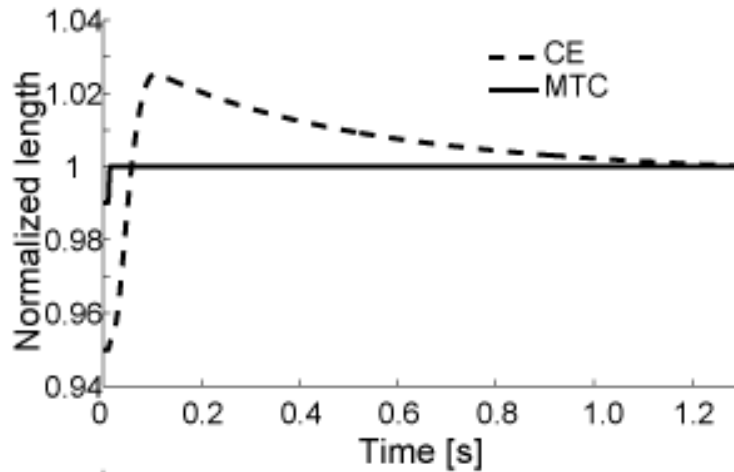

- Binding rate $f(x)$
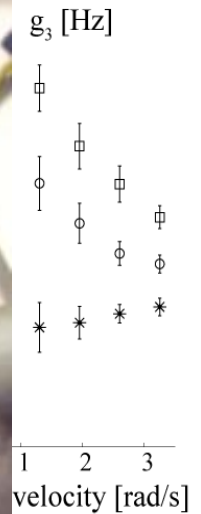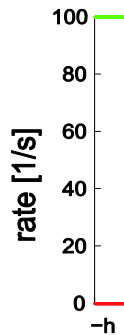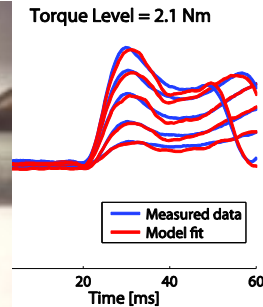- Unbinding rate $g(x)$

Huxley Muscle-tendon model
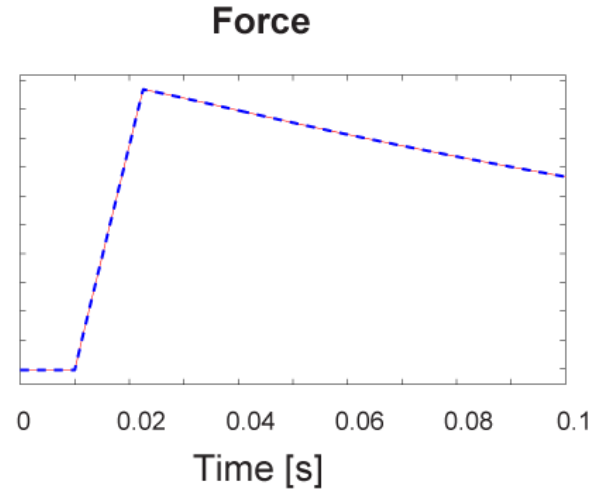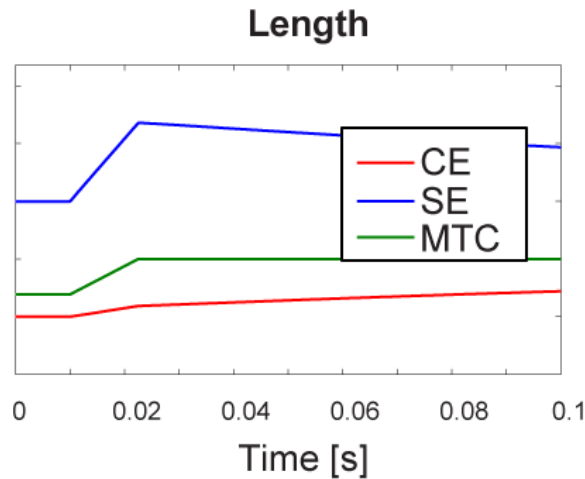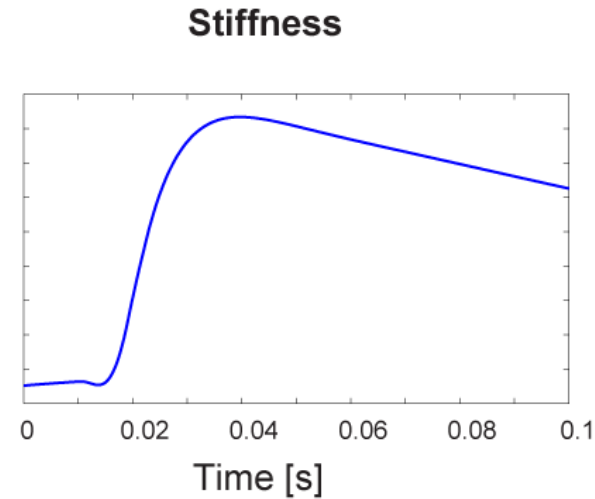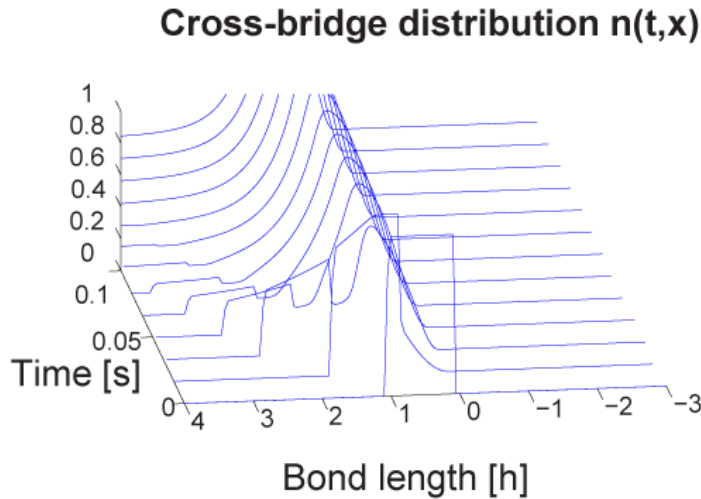
Huxley Muscle-tendon model

Huxley parameter estimation
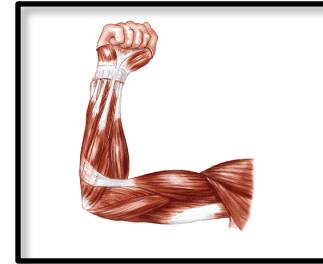
Stiffness in the Huxley model
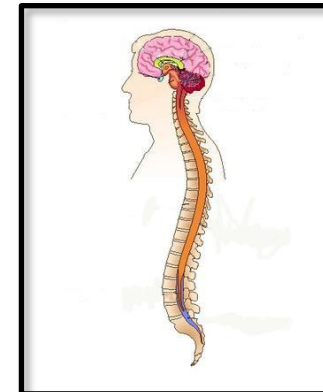
Stiffness in the Human joint

Physiology

- Muscle
- Ligaments
- Connective tissue

Control

- Neural activation
  - Co-contraction
- Reflexes

Conclusions

- Interpretation of Stiffness and damping depends* on
  - Muscle model
  - Measurement type

  *Schouten et al. *Biol Cybern* 2001
  Kistemaker et al. *PlosOne* 2011

- Estimates of neural activation depend on
  - Stiffness
  - Damping

Choose your model wisely

Thank you for your attention!