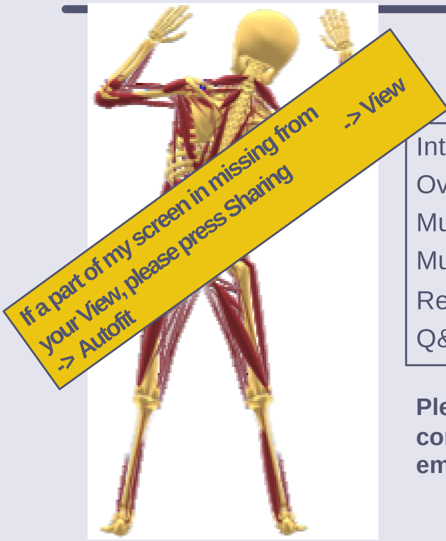
Muscle Modeling



The web cast will begin in a few minutes….

- Introduction (~5 min)
- Overview (~5 min)
- Muscle kinematics (~10 min)
- Muscle Models (~15 min)
- Recruitment (~5 min)
- Q&A session (~10 min)

Please check that your audio settings correspond to the instructions in the email you have received from us.

ANYBODY TECHNOLOGY

Presenters

John Rasmussen
(Presenter)

Arne Kiis
(Host)

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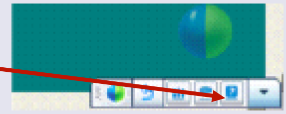
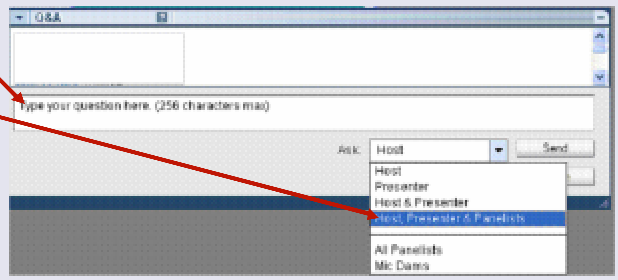
Q&A Panel

- Søren Tørholm
- Launch the Q&A panel here.
- Type your questions in the Q&A panel.
- Send the question to ”Host, Presenter & Panelists”
- Notice the answer displays next to the question in the Q&A box. You may have to scroll up to see it.





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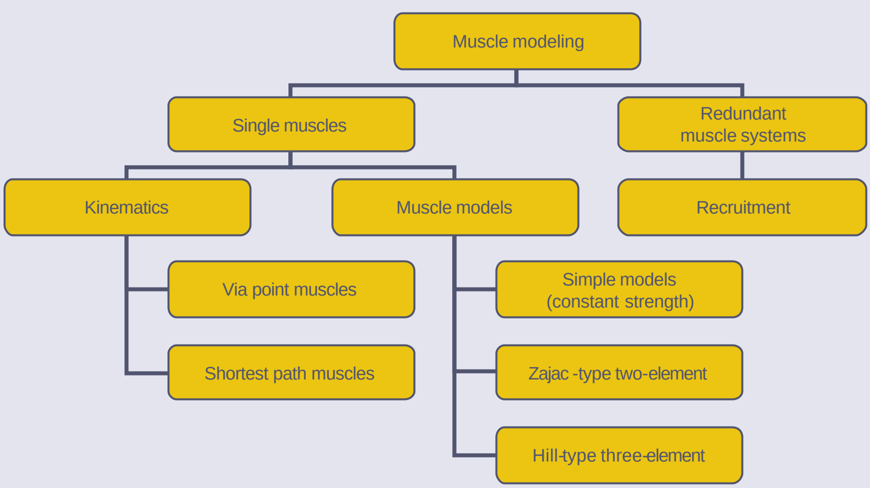
Muscle modeling overview



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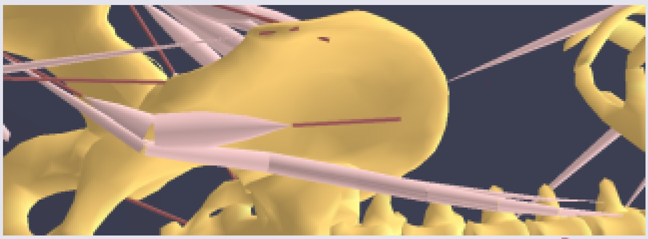
AnyViaPointMuscle

- Point-to-point-to-point… muscles
- Fixed points on skeleton segments
- Numerically very efficient
- Cannot establish and release contact



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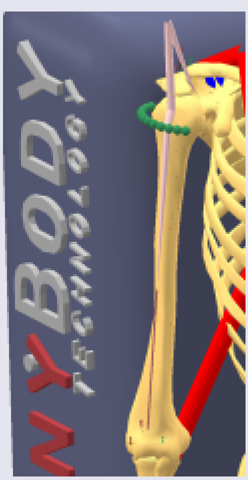
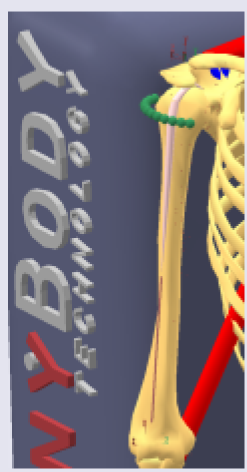
AnyShortestPathMuscle: Example



Biceps brachii caput longum is an AnyShortestPathMuscle. It wraps on the humeral head

The initial wrap position vectors spans the muscle



The kinematics of the muscle has been solved

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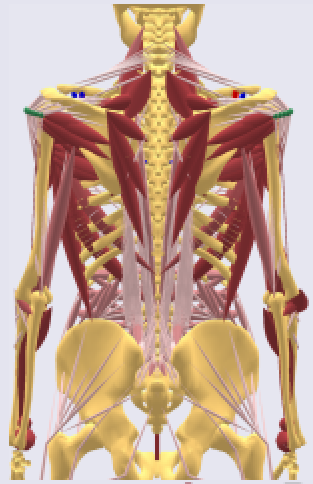
Multiple wrapping muscles

- Most of the muscles in the upper body wrap over the bones.
- The shoulder muscle action is very different depending on the posture of the body.



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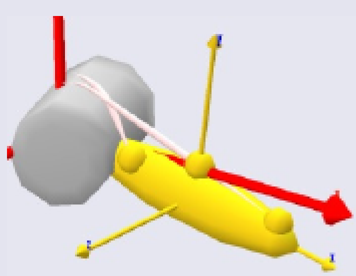
AnyShortestPathMuscle definition

```
AnyShortestPathMuscle Muscle1 = {
  AnyMuscleModel &Model = .SimpleModel;
  AnyRefFrame &Orig = .GlobalRef.M1Origin;
  AnySurface &srf = .GlobalRef.CylCenter.WrapSurf;
  AnyRefFrame &Ins = .Arm.M1Insertion;
  SPLine.StringMesh = 20;
};
```



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Muscle models

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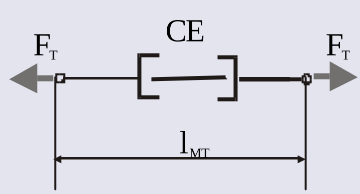
AnyMuscleModel

- The simplest muscle model in the system
- Merely a constant strength independent of operating characteristics

```
AnyMuscleModel SimpleModel = {
  F0 = 100;
};
```



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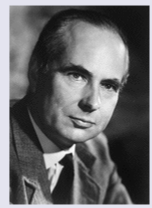
Muscle model types

- Hill models (A.V. Hill, 1886-1977, Nobel prize 1922).
  - Phenomenological model based on experiments with frog muscles.
  - Simple mathematical expression based on fiber length and contraction velocity.
- Cross bridge models (A.F. Huxley, b. 1917, Nobel prize 1963)
  - Based on the actual physiology and biochemistry of muscle contraction
  - Takes the form of differential equations with many input parameters that are hard to find.

Hill



Huxley

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Muscle models in musculoskeletal simulation

Traditional muscle models

Muscle models in inverse dynamics

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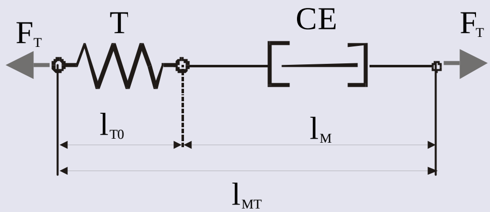
Zajac's Two-element muscle model AnyMuscleModel2ELin



Obligatory-Initialization Members

Class	Name	Description
AnyVar	F0	The nominal strength, i.e., the maximal isometric muscle force.
AnyVar	Lfbar	Nominal fiber length.
AnyVar	Lt0	Nominal tendon length.
AnyVar	Epsilonbar	Nominal tendon strain, i.e., the strain at the isometric muscle force in the serial elastic element.
AnyVar	V0	Maximum contraction velocity.

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AnyMuscleModel2ELin

$$F_i(L_{im}, v_i) = a_i(t)\, F_{i0} \left(2 \frac{L_{im}}{L_{i0}} - 1 \right) \left(1 - \frac{\dot{L}_{im}}{v_0} \right)$$

- Not exactly state-of-the-art, but simple and good for some purposes.
- Takes some amount of contraction dynamics into account.
- Disregards passive elasticity
- Undesirable ability to switch the force off when the muscle is stretched passively.

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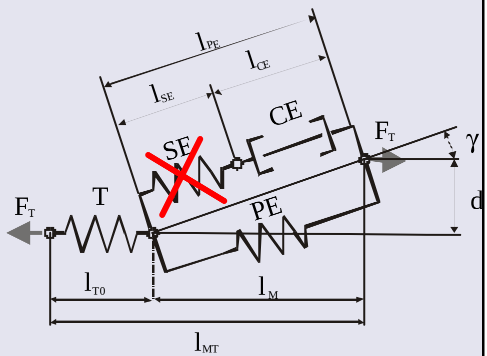
Three-element Hill model AnyMuscleModel3E

CE Hill type contractile element, models the force/length and force/velocity characteristic

PE Parallel elastic element, models the passive properties.

T Elastic tendon

Numerical solution necessary!



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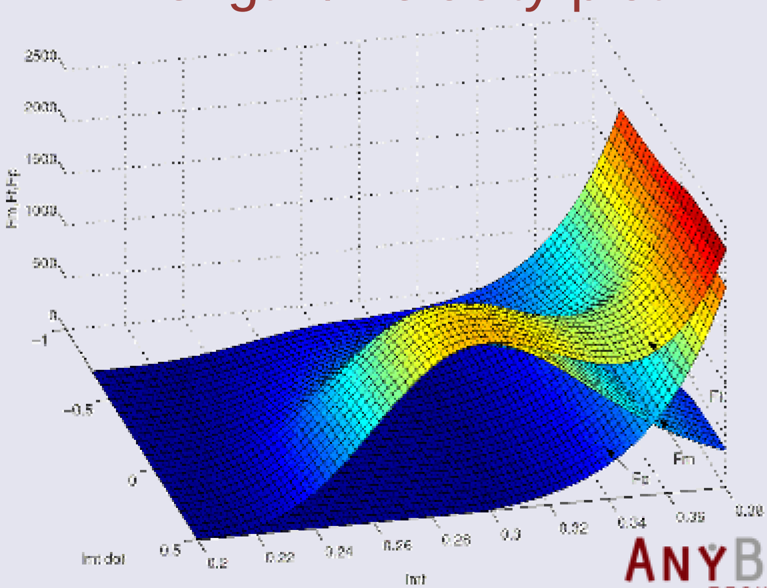
Length / velocity plot



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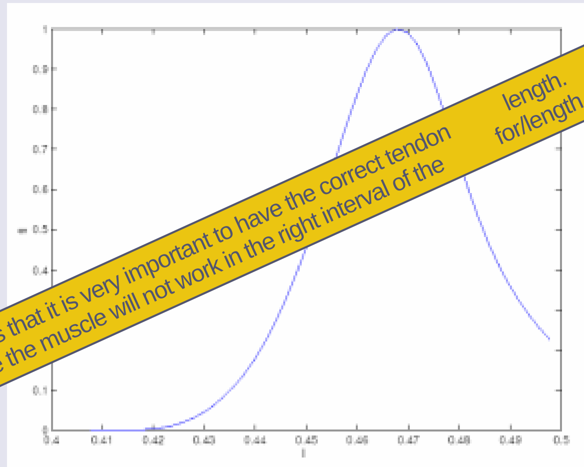
Force length relation



This means that it is very important to have the correct tendon length.
Otherwise the muscle will not work in the right interval of the for/length curve.

Gastrocnemius strength as a function of muscle length

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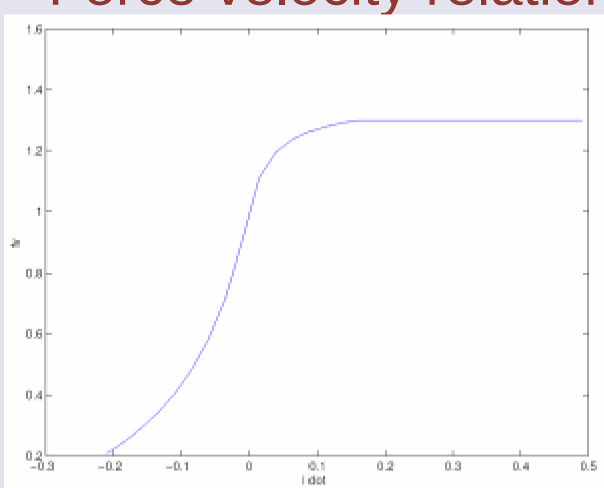
Force velocity relation



Gastrocnemius strength as a function of muscle length

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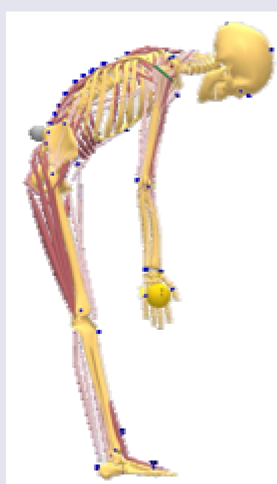
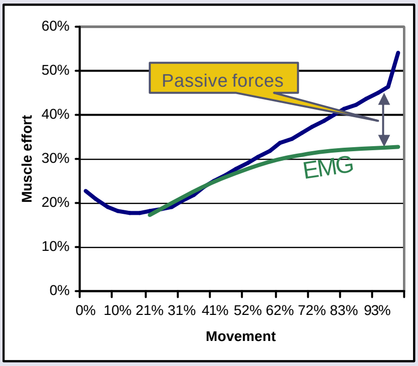
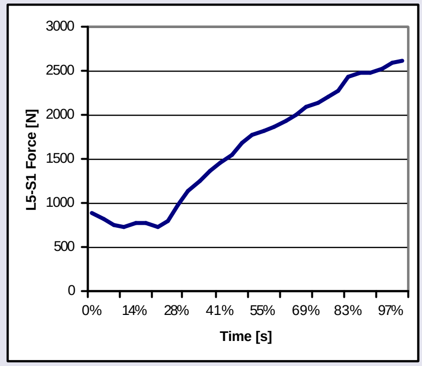
Demo: Passive muscle forces in bicycling

Example: Spine extension



AnyBody with simple muscle model





One-element model: Reasonable joint forces
Two-element model: Also reasonable muscle activities
Three-element model: Also division between active and passive forces.

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Recruitment

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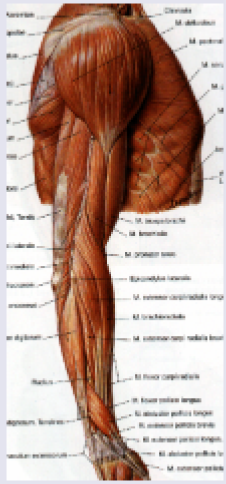
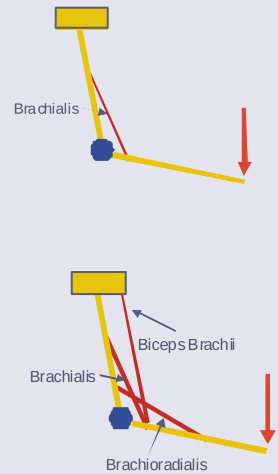
Redundancy

We have ”too many” muscles. This creates a situation of statical indeterminacy.

In statically indeterminate elastic problems, the load is divided according to the elasticity of the structure.

In biological systems, the load is distributed by the central nervous system.





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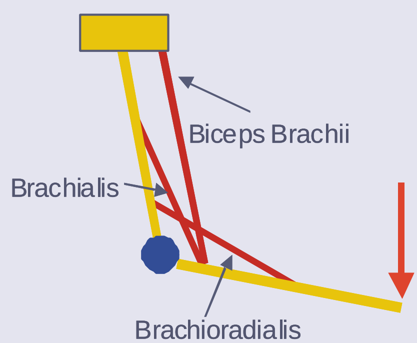
What do we know about muscle recruitment from experiments?

- Muscles crossing the same joint cooperate when they can.
- Some muscles can be observed to work against the movement and perform negative work.
- The pattern of muscle activation for repeated movements is very similar. This indicates that a rational criterion is behind the recruitment.
- When the load over a joint is increased, the muscle tones also increase until maximum is reached.



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Equilibrium

Internal forces

Applied forces

Joint reactions

Muscle forces

$$\mathbf{Cf} = \mathbf{d}, \text{ where } \mathbf{f} = [\mathbf{f}^{(\mathbf{R})}, \mathbf{f}^{(\mathbf{M})}]$$

$$f_i^{(M)} \geq 0, \qquad i \in \{1,..,n^{(M)}\}$$

The matrix $\mathbf{C}$ is rectangular. This means that there are infinitely many solutions to the system of equations. How to pick the right one?

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Optimality

Minimize

$$G(\mathbf{f}^{(\mathbf{M})})$$

Subject to

$$\mathbf{Cf} = \mathbf{d}$$

$$f_i^{(M)} \geq 0, \qquad i \in \{1,..,n^{(M)}\}$$

Objective function. Different choices give different muscle recruitment patterns.

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Choices of objective function

$$G(\mathbf{f}^{(\mathbf{M})}) = \sum_i \left(\frac{f_i}{N_i} \right)^p$$

- p = 1: This will fail to produce muscle synergism for small loads.
- p > 1: Muscle synergism but additional constraints are necessary to avoid overloaded muscles
- p ? 8: Maximum synergism, minimum fatigue.
- All criteria with p > 1 predict synergism (and sometimes antagonism)

Minimum fatigue formulation

Minimize maximum relative muscle load or minimize fatigue or maximize endurance

Minimize

$$\max\left(\frac{f_i}{N_i}\right), \quad i \in \{1,..,n^{(M)}\}$$

Muscle force

Muscle strength as a function of length and velocity.

Subject to

$$\mathbf{Cf} = \mathbf{d}$$

Equilibrium equations

$$f_i^{(M)} \geq 0, \quad i \in \{1,..,n^{(M)}\}$$

Muscles cannot pull

Bound formulation and muscle strength

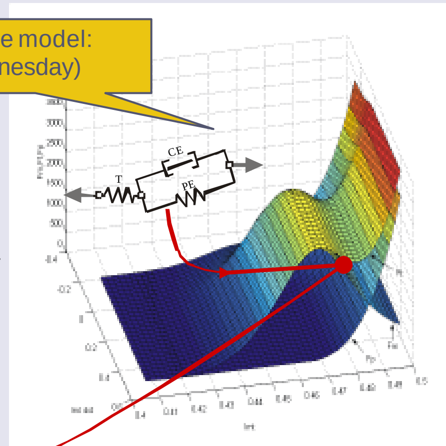
$$\min_{\mathbf{f},b} \; b$$

Subject to

$$\mathbf{Cf} = \mathbf{d}$$

$$f_i^{(M)} \geq 0, \quad i \in \{1,\ldots,n^{(M)}\}$$

$$\frac{f_i^{(M)}}{N_i} \leq b, \; i \in \{1,\ldots,n^{(M)}\}$$



Muscle strength N as a function of muscle length and velocity

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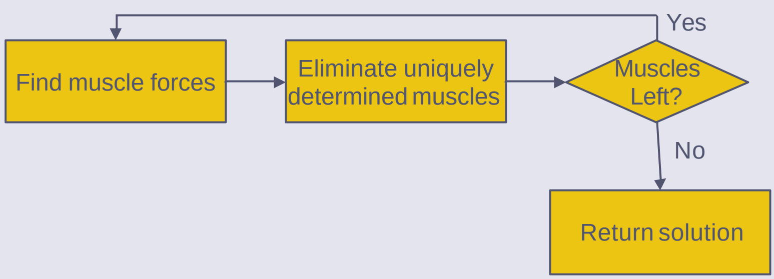
Iterative solution is necessary



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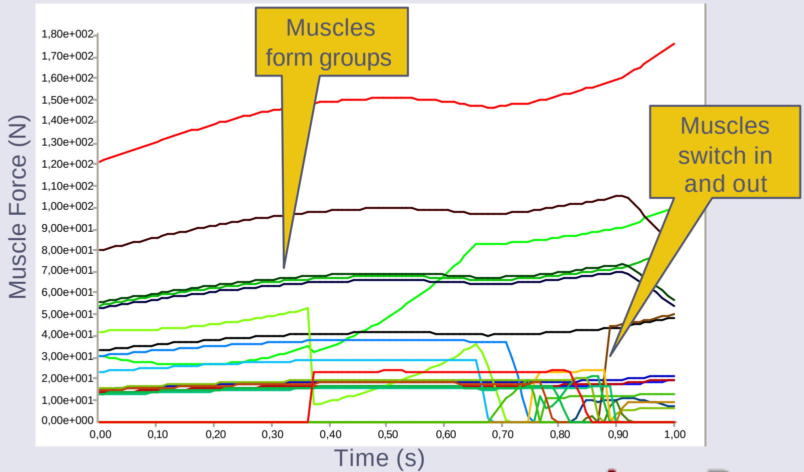
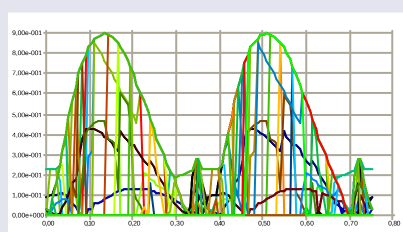
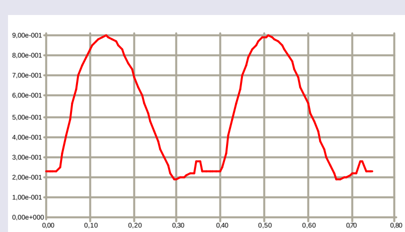
Effects of the min/max criterion



The envelope

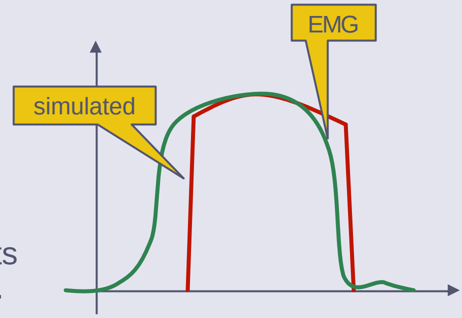
- The envelope of muscle activity is a good measure of fatigue.
- The envelope is very numerically stable.
- The envelope is a good choice of criterion for ergonomic design problems.





Inverse dynamics assumptions

- Does not take activation dynamics into account.
  - Sharper activity kinks
  - Later onset compared to EMG
- Disregards certain dynamic effects such as wobbly masses.
- Assumes that movements are voluntary and skilled.
- Some people believe that
  - QP recruitment is the best for low activity
  - Min/max is the best for high activity



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Additional information

- References at www.anybody.aau.dk
- At www.anybodytech.com:
  - Tutorials
  - Reference manual
  - Download a free 30 day demo license

Q&A session!

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