Muscle Mechanics

Goals:

1. Muscle Mechanics
2. EMG
3. Kinematics

The Motor Unit

- smallest subunit that can be controlled
  - innervated separately by motor neurons
  - synaptic junction in ventral root of spinal cord
  - 3-2000 muscle fibers

Recruitment of Motor Units

- muscle have finite number of motor units
  - each unit is controlled separately
  - excitation is all or nothing!

    motor neuron action potential $\rightarrow$ muscle twitch

How to increase tension?

1. increase rate of stimulation
2. stimulate more motor units $\rightarrow$ **motor recruitment**

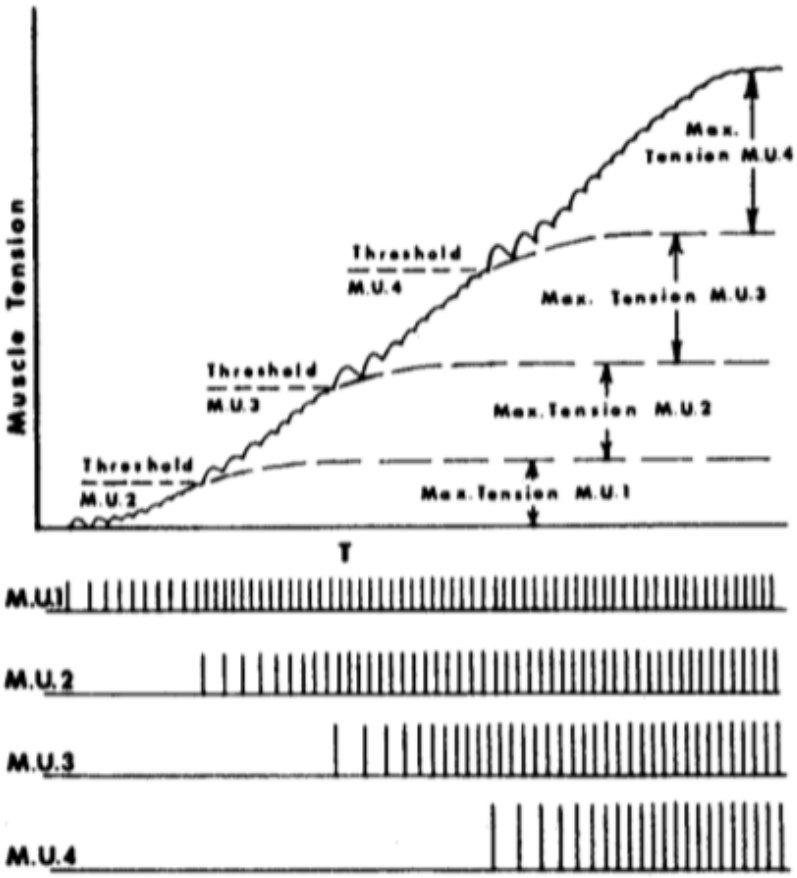
Size Principle

Size of newly recruited motor units increase with tension level

Smaller motor units fire first!

What about when tension is decreasing?
Other way around larger units stop first.

Max firing rates: 120 Hz



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Types of Motor Units

Tonic Units - smaller slow-twitch motor units

- rich in mitochondria
- highly capillarized
- high capacity for aerobic metabolism
- low peak tension
- long time to peak

Phasic Units - larger fast-twitch motor units

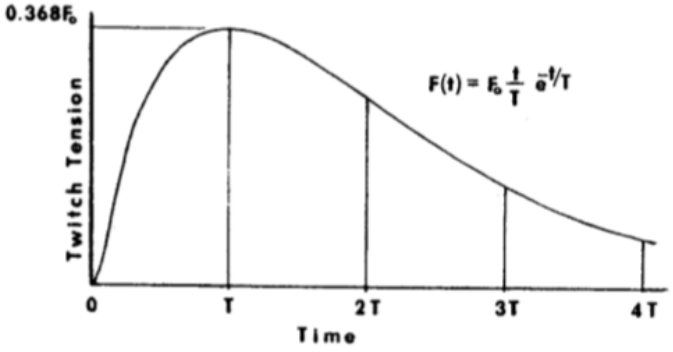
- less mitochondria
- poorly capillarized
- rely on for anaerobic metabolism
- larger peak tension
- short time to peak

The Muscle Twitch

- smallest unit of tension
- Model as impulse response of second order critically damped system (isometric voluntary contraction)

$$F(t) = F_0 \frac{t}{T} e^{-t/T}$$

- F_0 constant representing maximum tension
- T constant representing time till max tension



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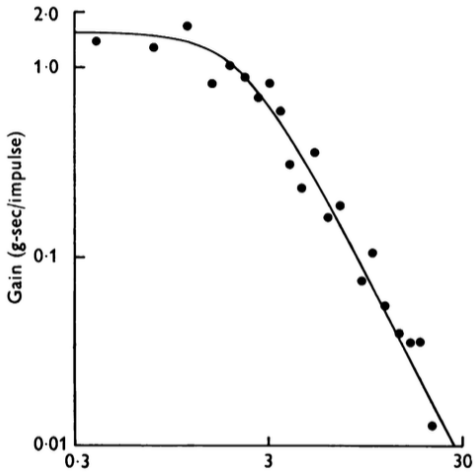
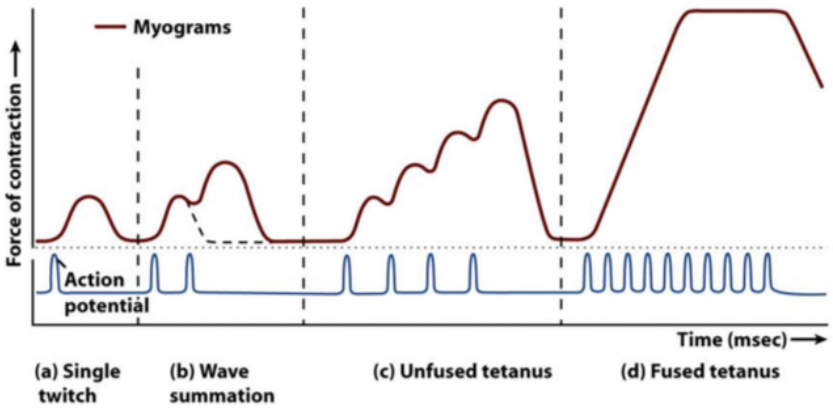
Where does this come from?
Experimentally determined in-vivo.
Recall general second order system:

$$\ddot{y}(t) + 2\zeta\omega_n\dot{y}(t) + \omega_n^2 y(t) = K\omega_n^2 u(t)$$



Milner-Brown, 1972

Sustained muscle tension?
Repeated twitches $\rightarrow$ tetanus



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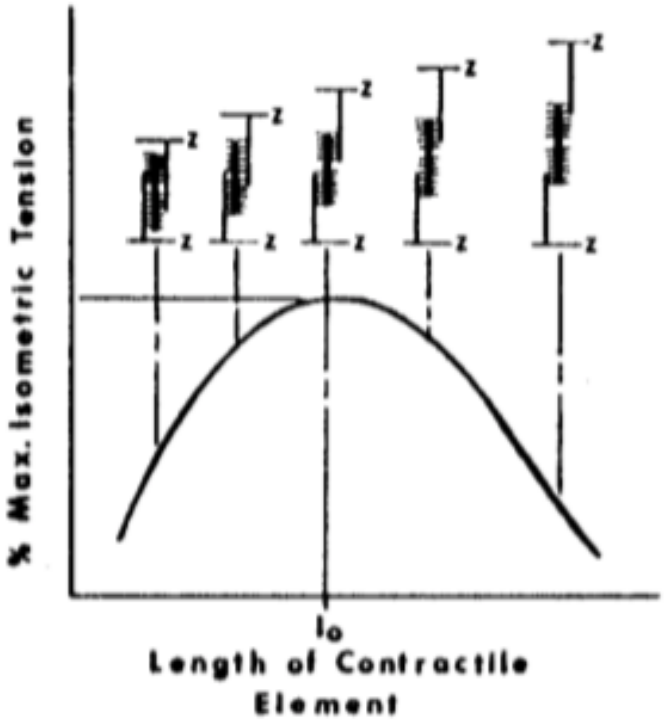
Muscle Force-Length Characteristics

Consider active element (contractile element)

- maximum force at resting length
- max cross bridges! $\rightarrow$ max tension!
- max length $\rightarrow$ no cross bridges
- min length $\rightarrow$ cross bridge interference



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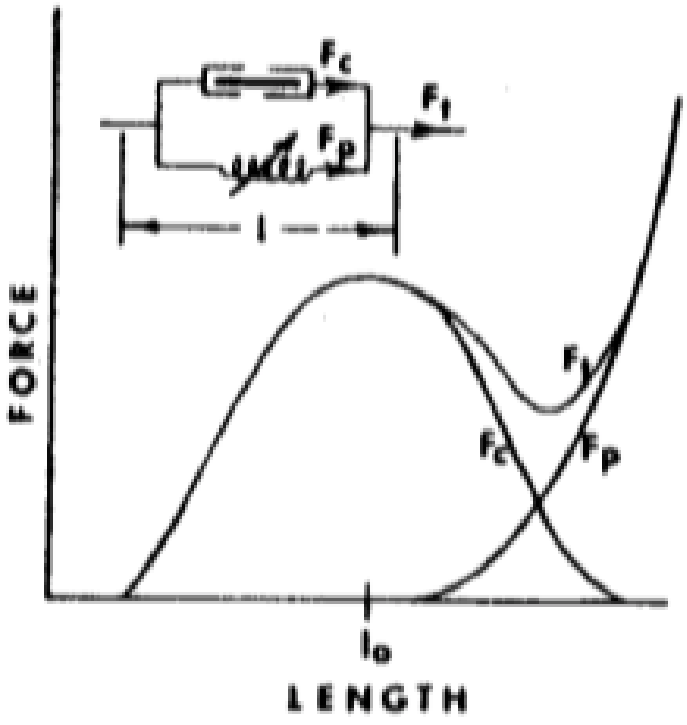
Consider active and parallel passive elements

- connective tissue surrounding contractile element influences the force-length curve
- acts like an elastic band
- nonlinear force-length relationship



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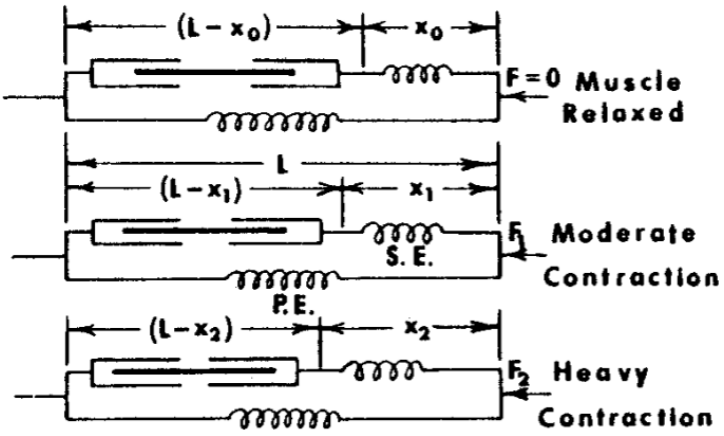
Consider active, parallel and series elements

- isometric contractions
- internal shortening $\rightarrow$ length stays constant $\rightarrow$ tension build up in series component



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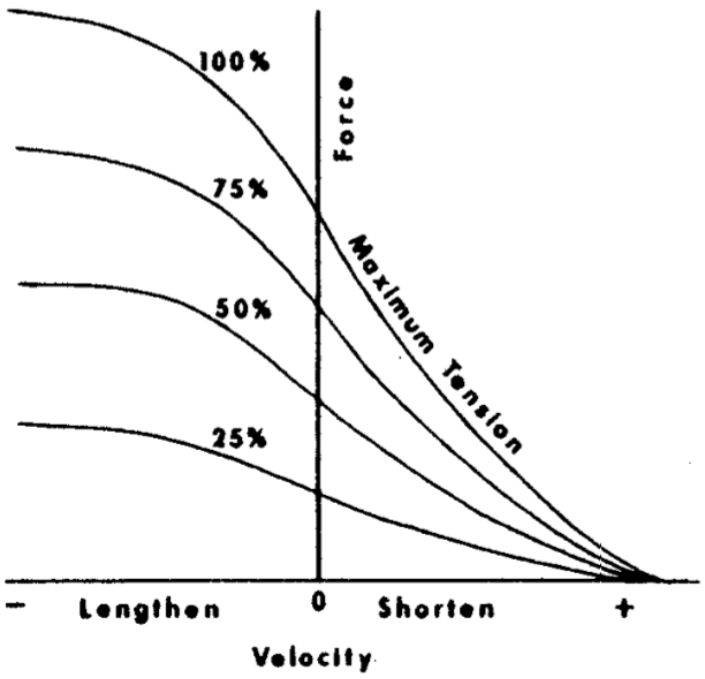
Muscle Force-Velocity Characteristics

Concentric Contraction

- concentric $\rightarrow$ shortening (positive work)
- tension decreasing as it shortens
  - loss in tension due to cross-bridges in the contractile element
  - fluid viscosity of contractile and parallel elements
- Hill model this thermodynamically in 1938

$$(P + a)(V + b) = (P_0 + a)b$$

P_0 – max isometric tension
a – coefficient of shortening heat
b – $a\frac{V_0}{P_0}$
V_0 – max velocity
This equation relates force-velocity, but only isotonic near resting length



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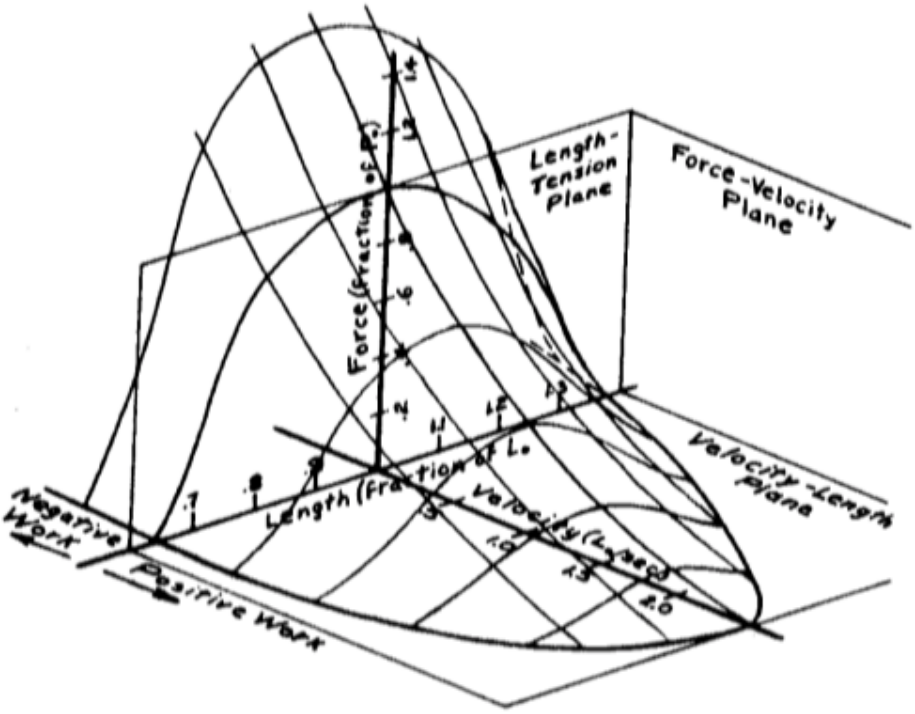
Eccentric Contraction

- eccentric $\rightarrow$ lengthening (negative work)
- think of this as mechanical breaking
- much harder to find experimentally

Muscle Force-Velocity-Length Characteristics



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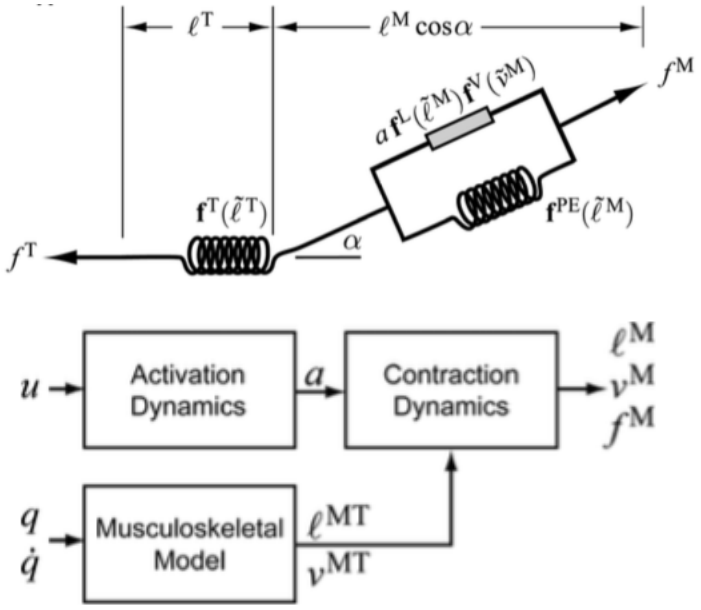
Muscle Models

- complete models (cross-bridge) have many parameters and can be hard to simulate, e.g, Huxley-based models
- most of the time we are interested in models from a 'system dynamic' perspective: input - output relationship

Hill type muscle models

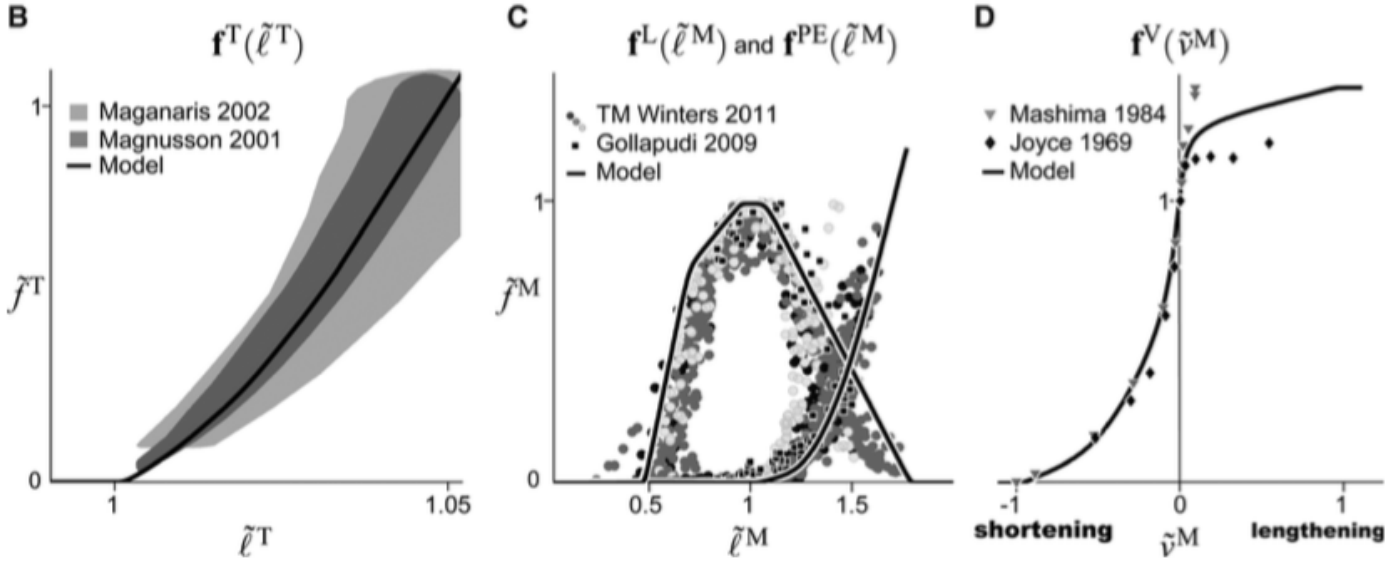
- simple, lumped parameter dimensionless model
- can captures input-output behavior
- assumes force generated by single fiber



Millard, 2013

$$\dot{a} = f(u, a)$$

$$f_o^M \left(a\mathbf{f}^L\left(\tilde{\ell}^M\right)\mathbf{f}^V\left(\tilde{v}^M\right) + \mathbf{f}^{PE}\left(\tilde{\ell}^M\right) \right) \cos\alpha - f_o^M \mathbf{f}^T\left(\tilde{\ell}^T\right) = 0$$



Millard, 2013

Electromyography

Motor Unit Action Potential (MUAP)

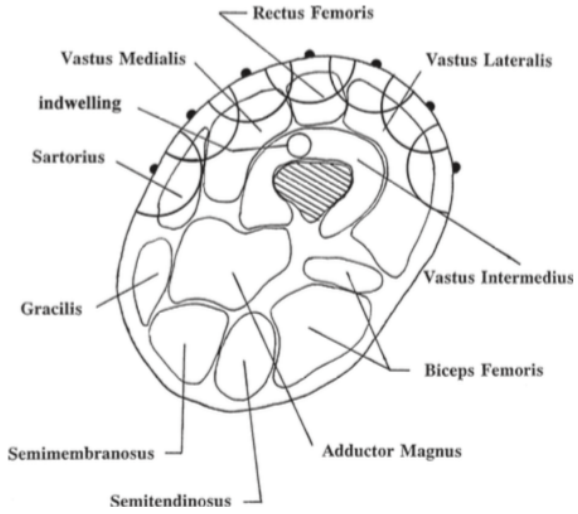
- muscle tissue conducts electrical potentials
- electrodes placed on top (surface) or inside (indwelling) the muscle can record the algebraic sum of (MUAP)

Sequence of events

1. action potential from motor neuron arrives at motor plate
2. triggers neurotransmitter (ACh) to be released
3. depolarization of postsynaptic membrane
4. MUAP starts at Z-line
5. spreads along traverse tubular system (EMG sees this)

Cross-talk

- overlapping electrode region
- test with cross-correlation



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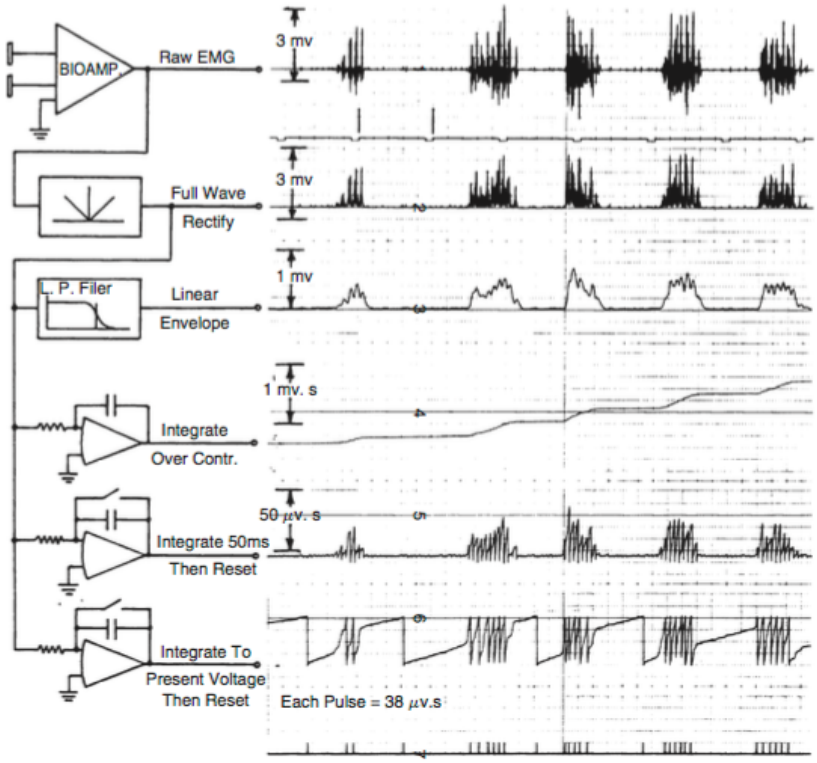
Processing



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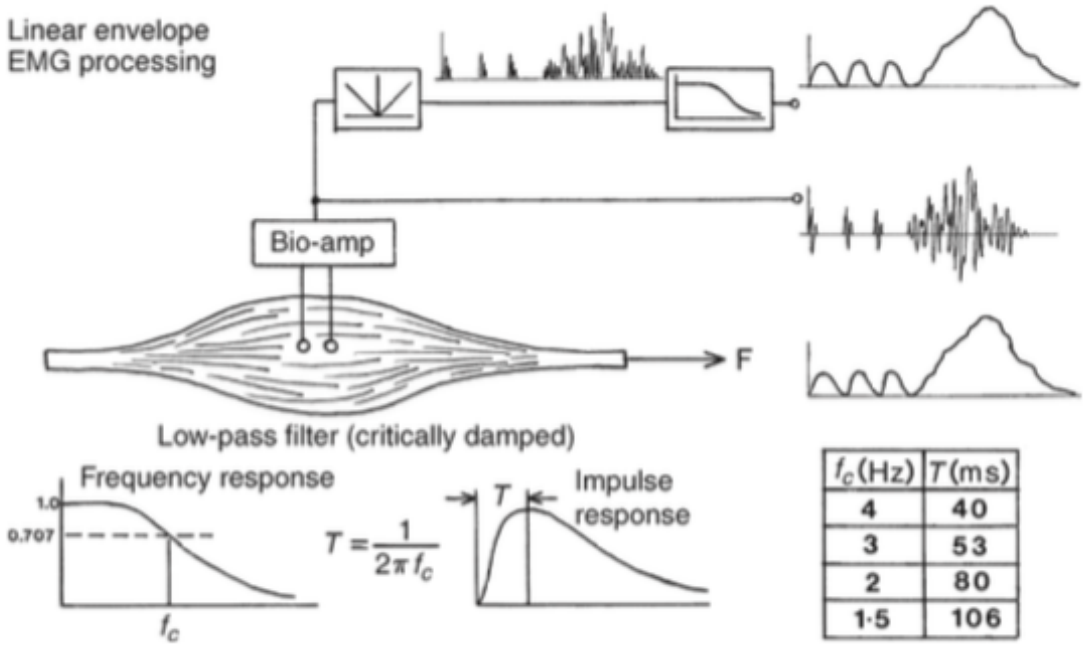
Force estimates for isometric contractions



f_c (Hz)	T (ms)
4	40
3	53
2	80
1·5	106

Winter, 2009