Muscle Mechanics

Summary of Muscle Activation & Contraction

- Motor neuron stimulates muscle.
  - AP travels down T tubules
- Depolarization of membrane triggers release of Ca^{2+} from SR.
- Ca^{2+} binds to troponin.
  - Troponin & tropomyosin reorganize to expose myosin binding site on actin

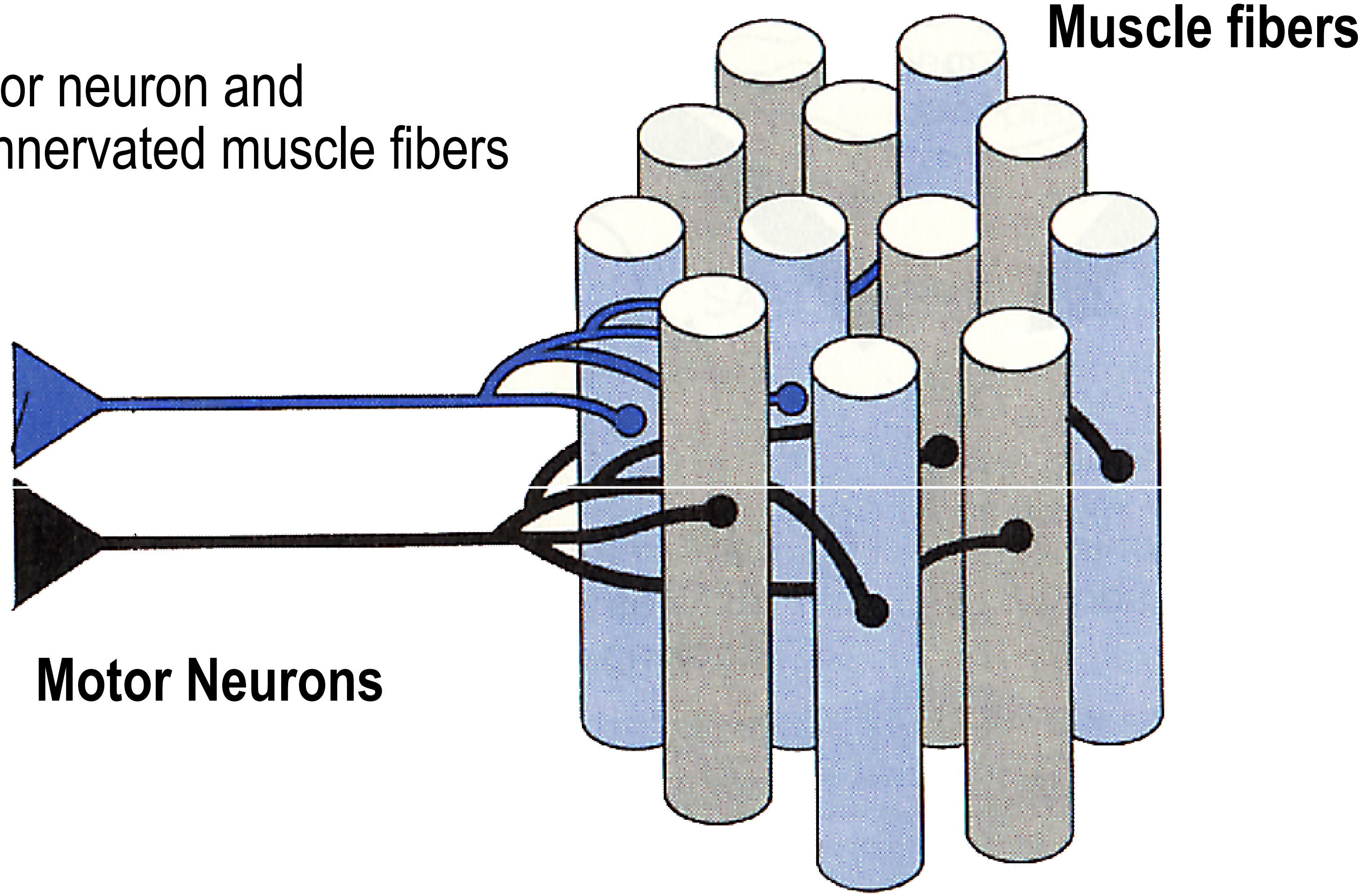
Summary continued

- Breakdown of ATP allows myosin head to attach & detach from actin (cross-bridge cycle).
  - When cross bridges form (and energy is released), force is developed
- Myosin (thick filament) pull along actin (thin filament) and Sarcomere shortens (sliding filament theory).
- Sarcomeres shorten and muscle shortens pulling on elastic or skeletal elements resulting in movement.

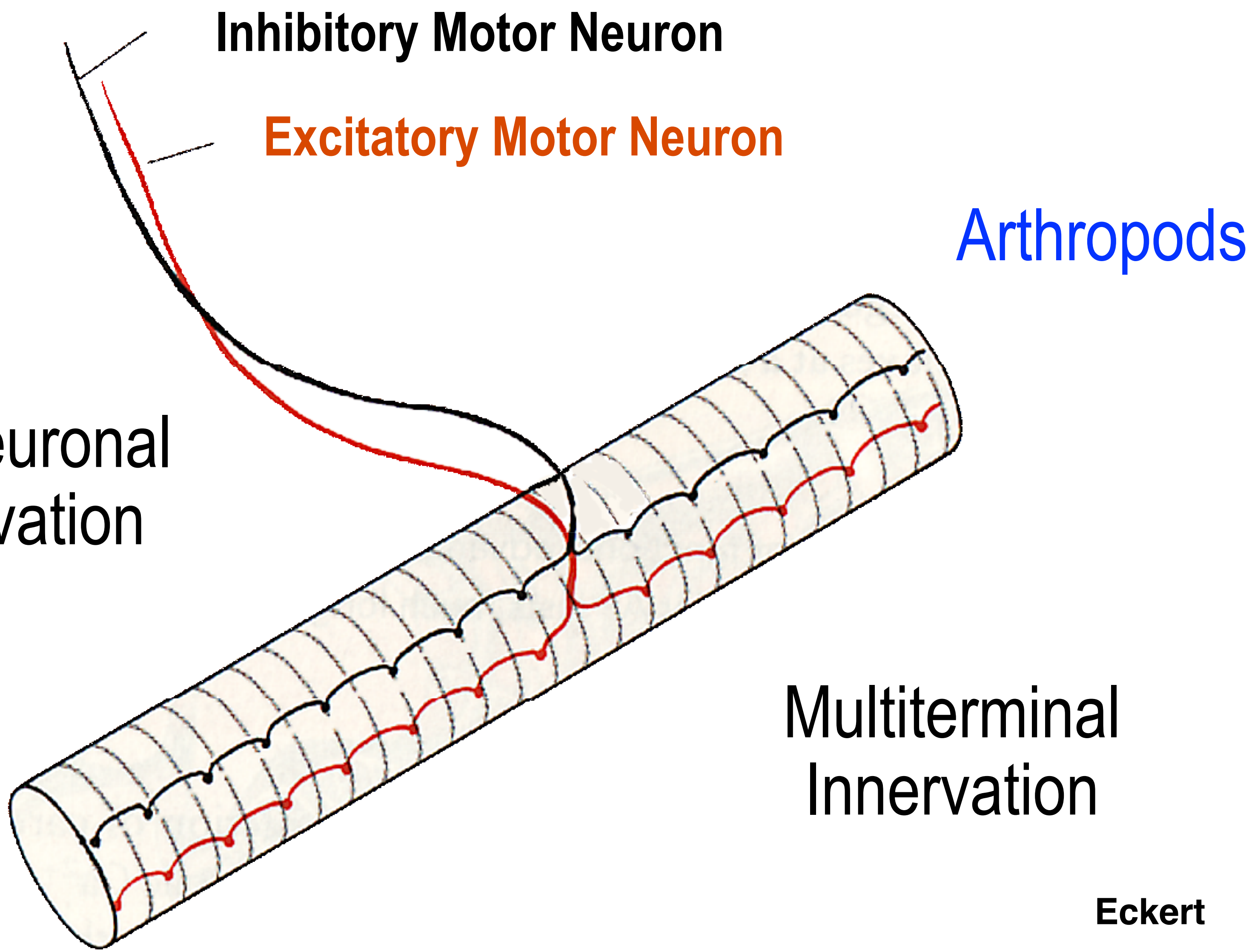
Motor Unit Recruitment

Motor unit

- motor neuron and its innervated muscle fibers



Innervation and Control



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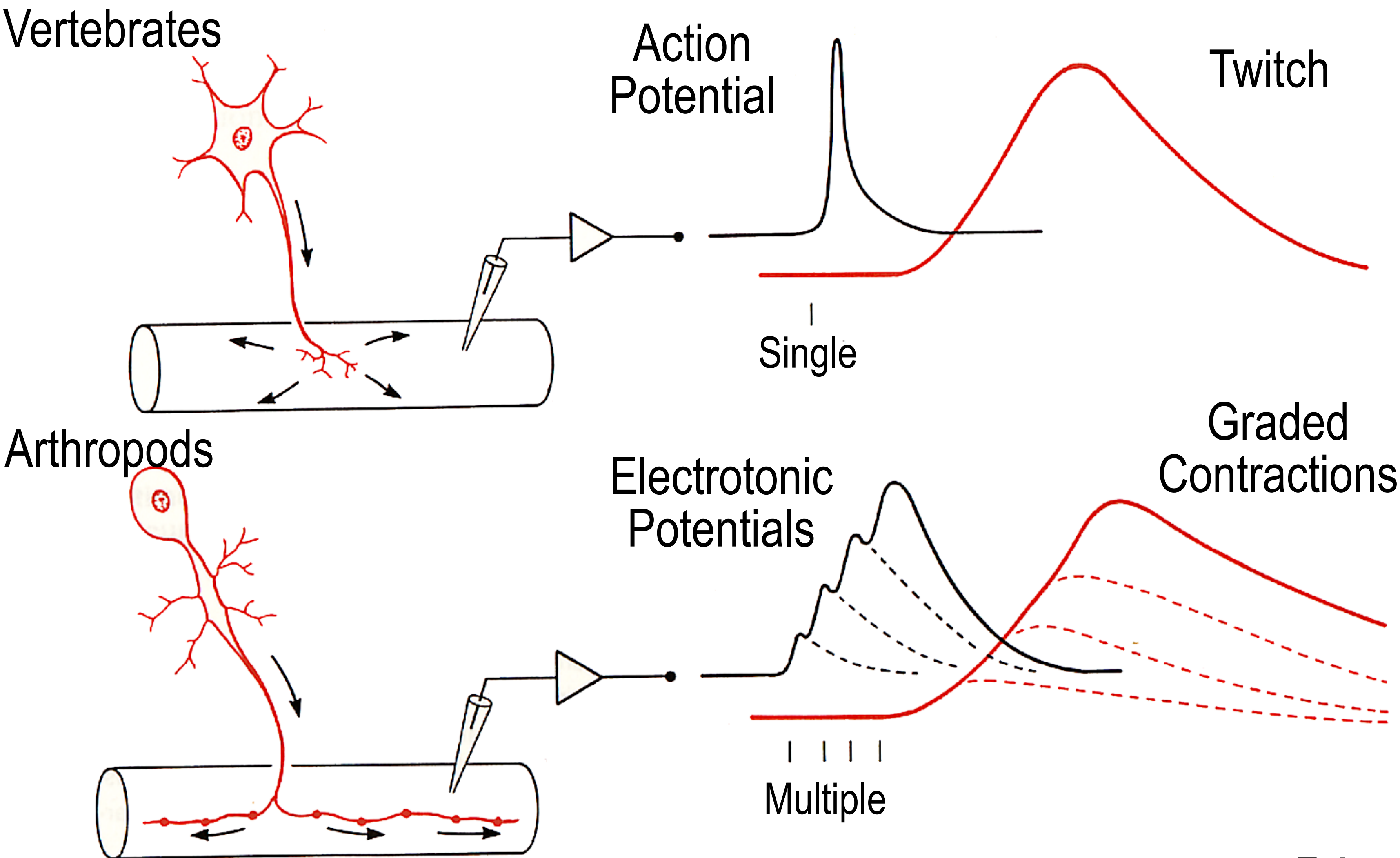
Control Strategies



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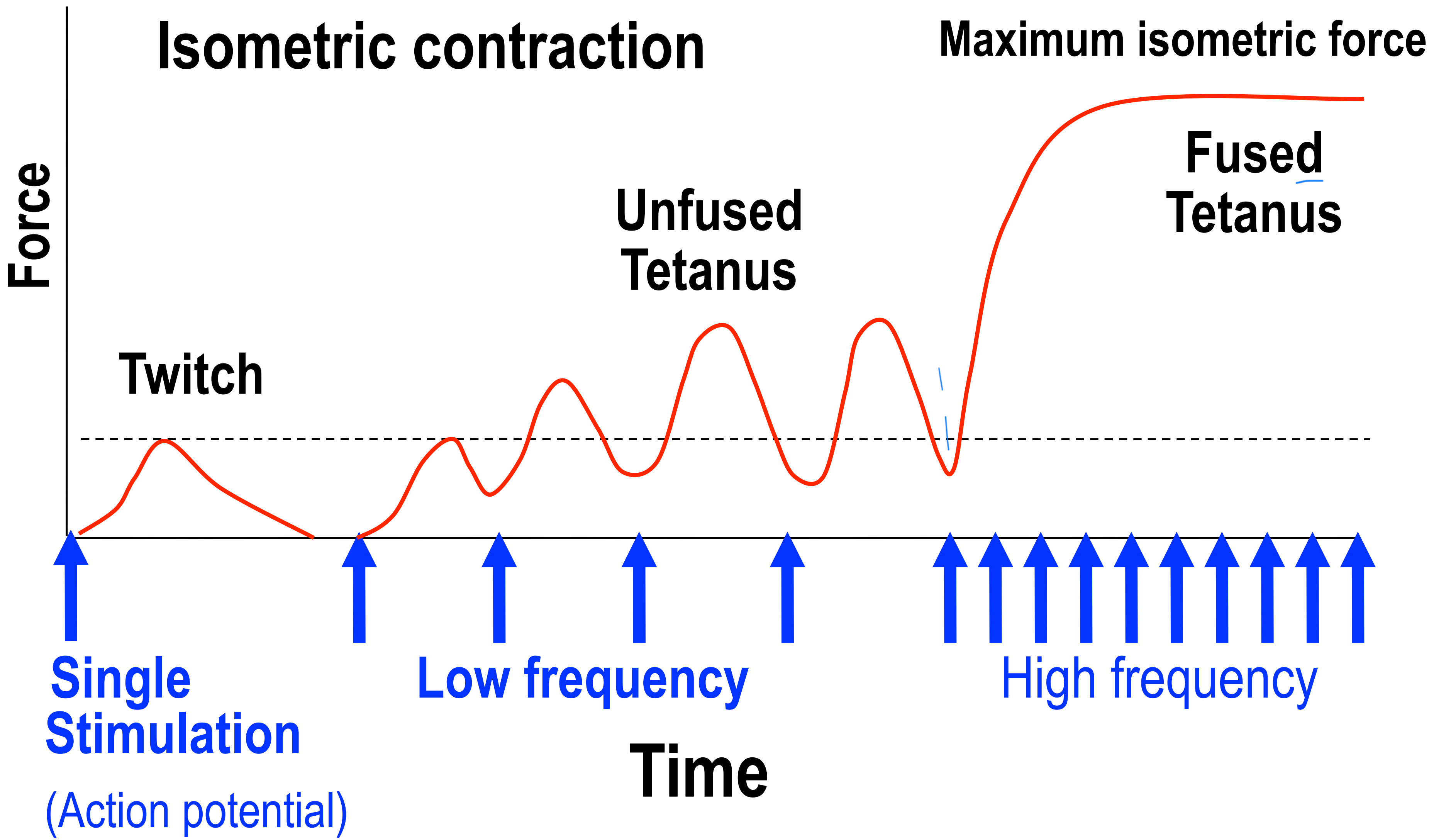
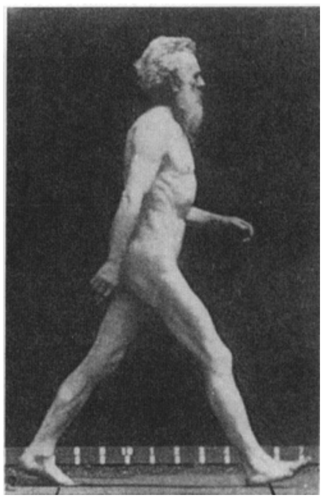
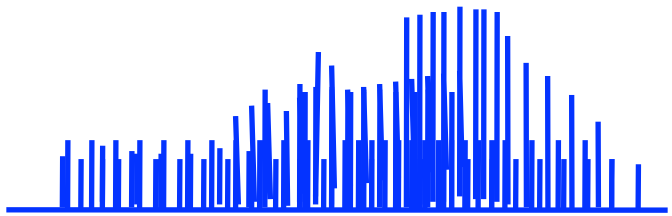
Activation and Summation



Activation

Human

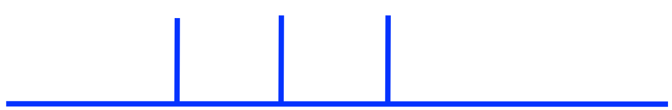




Stimulation (EMG)

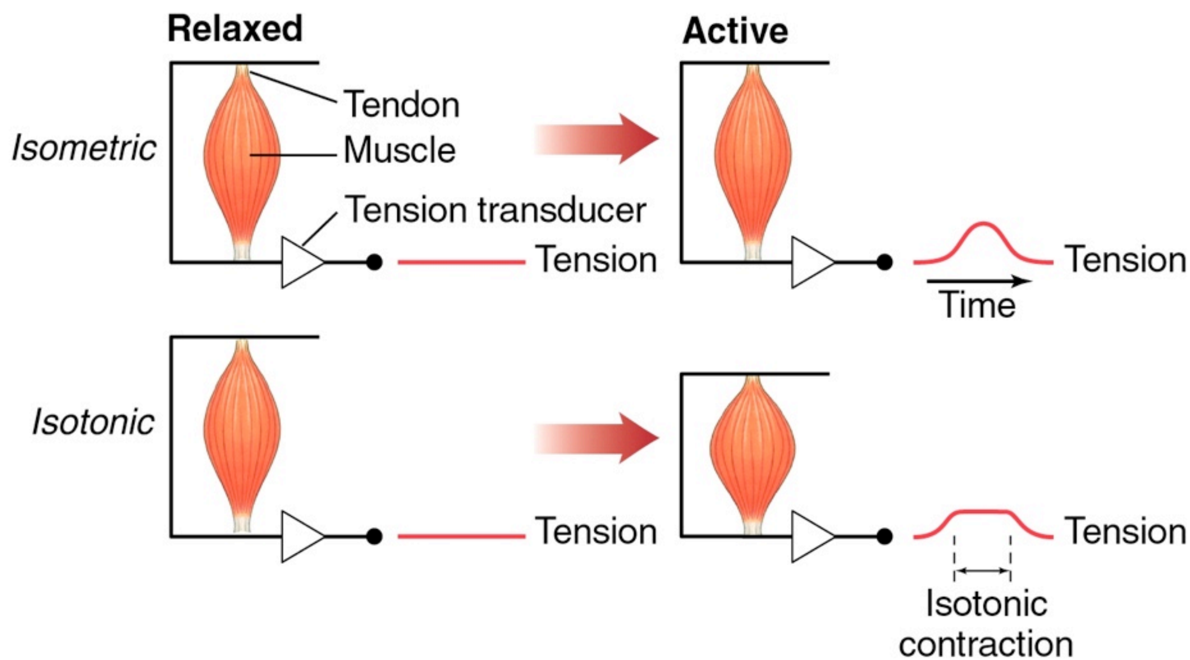
Muscle Force

Cockroach

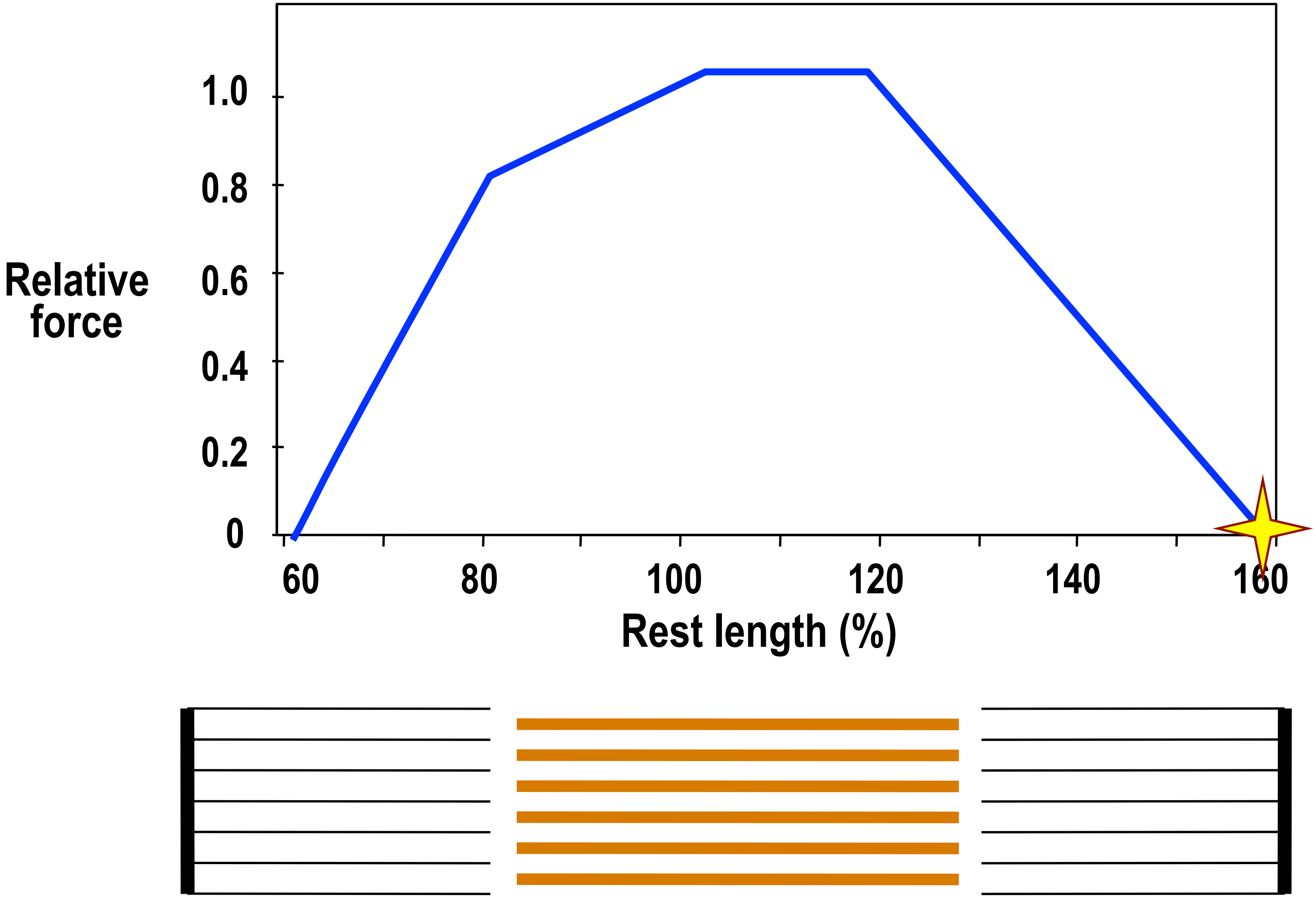


Function of Muscles is to Produce Force/ Movement

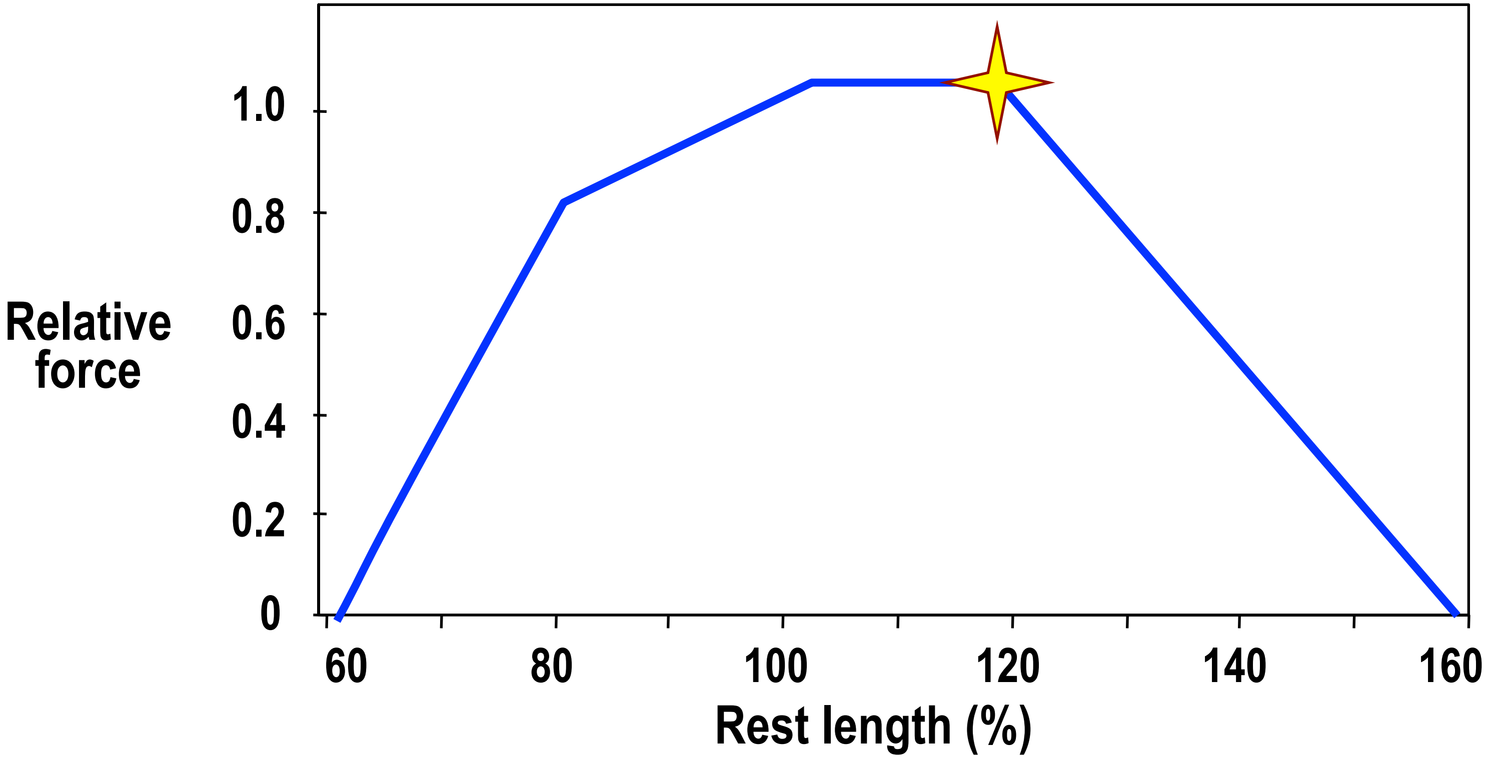
- Important Factors in force development
  - Length of Sarcomeres
  - Velocity of shortening

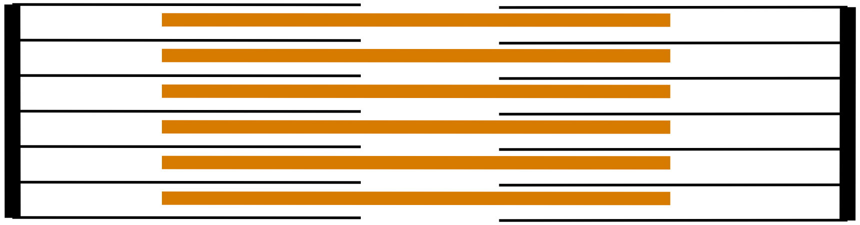


Length Effects Force (Length-tension curves)

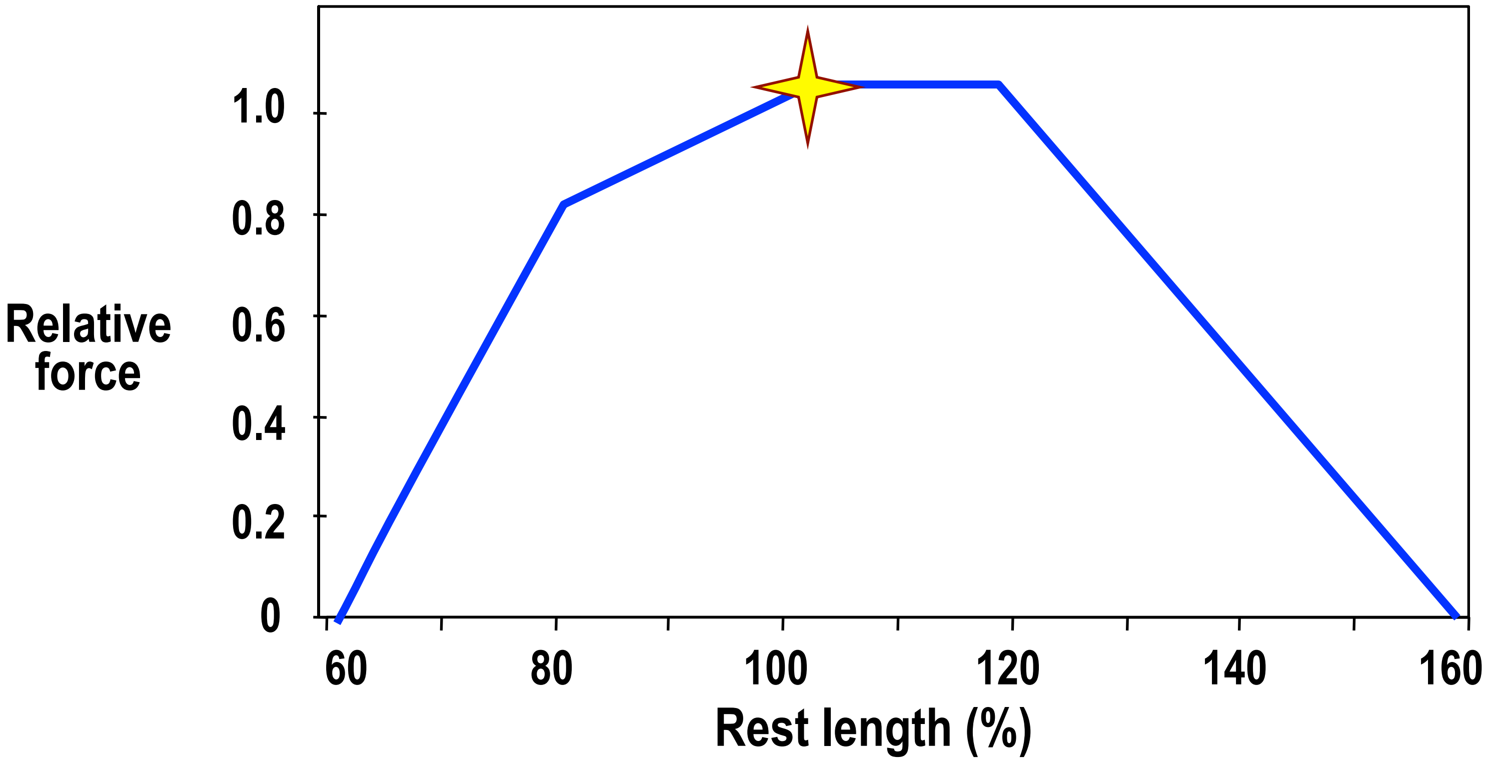


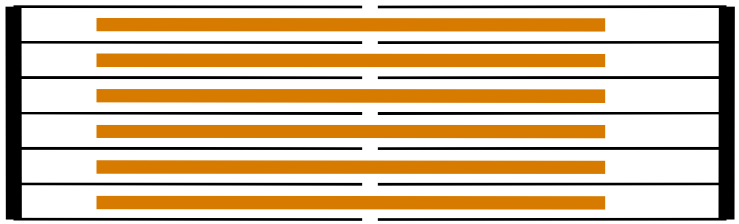
Length-tension curves continued



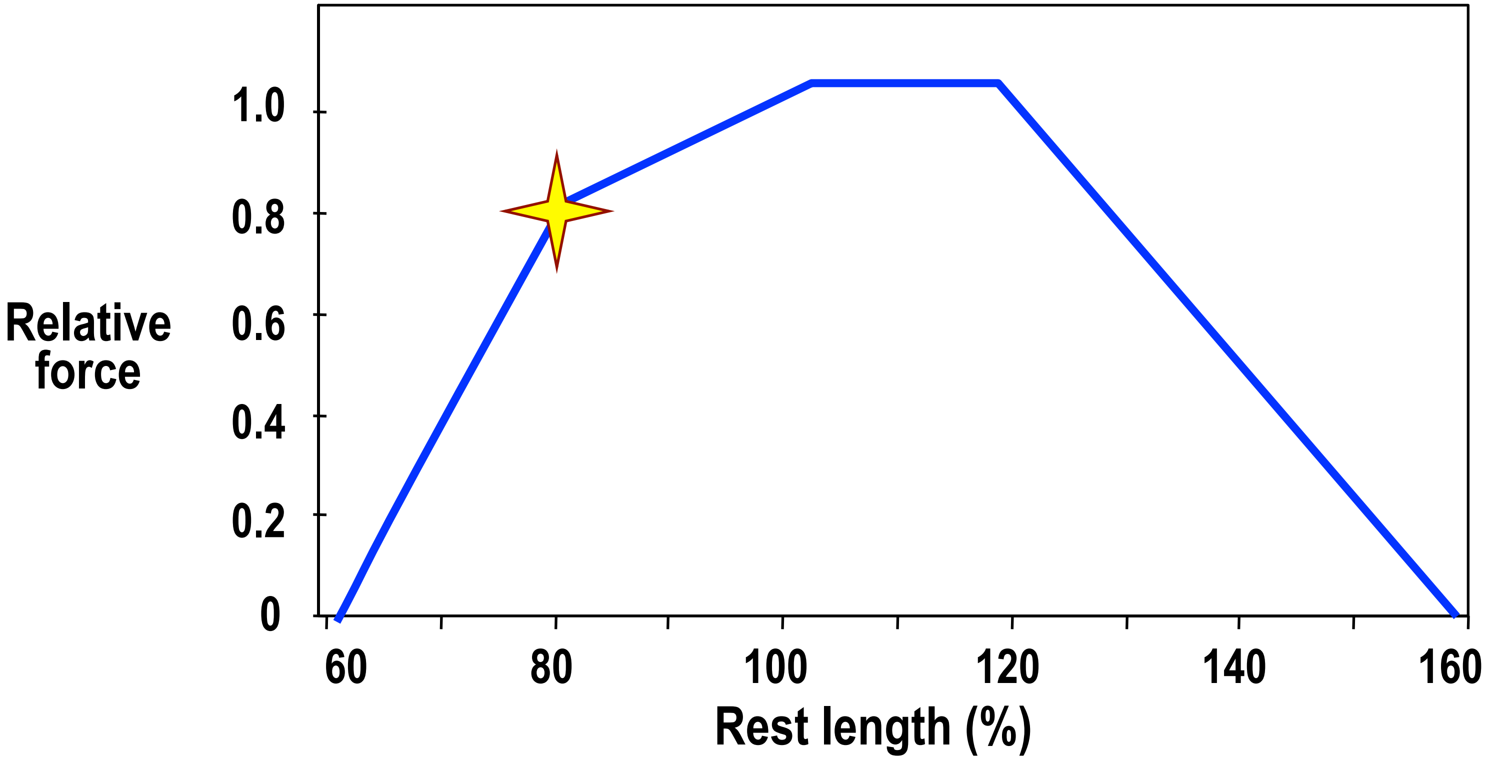


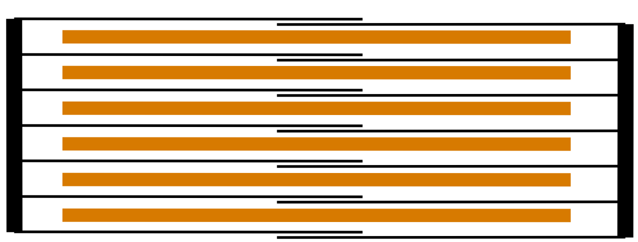
Length-tension curves continued



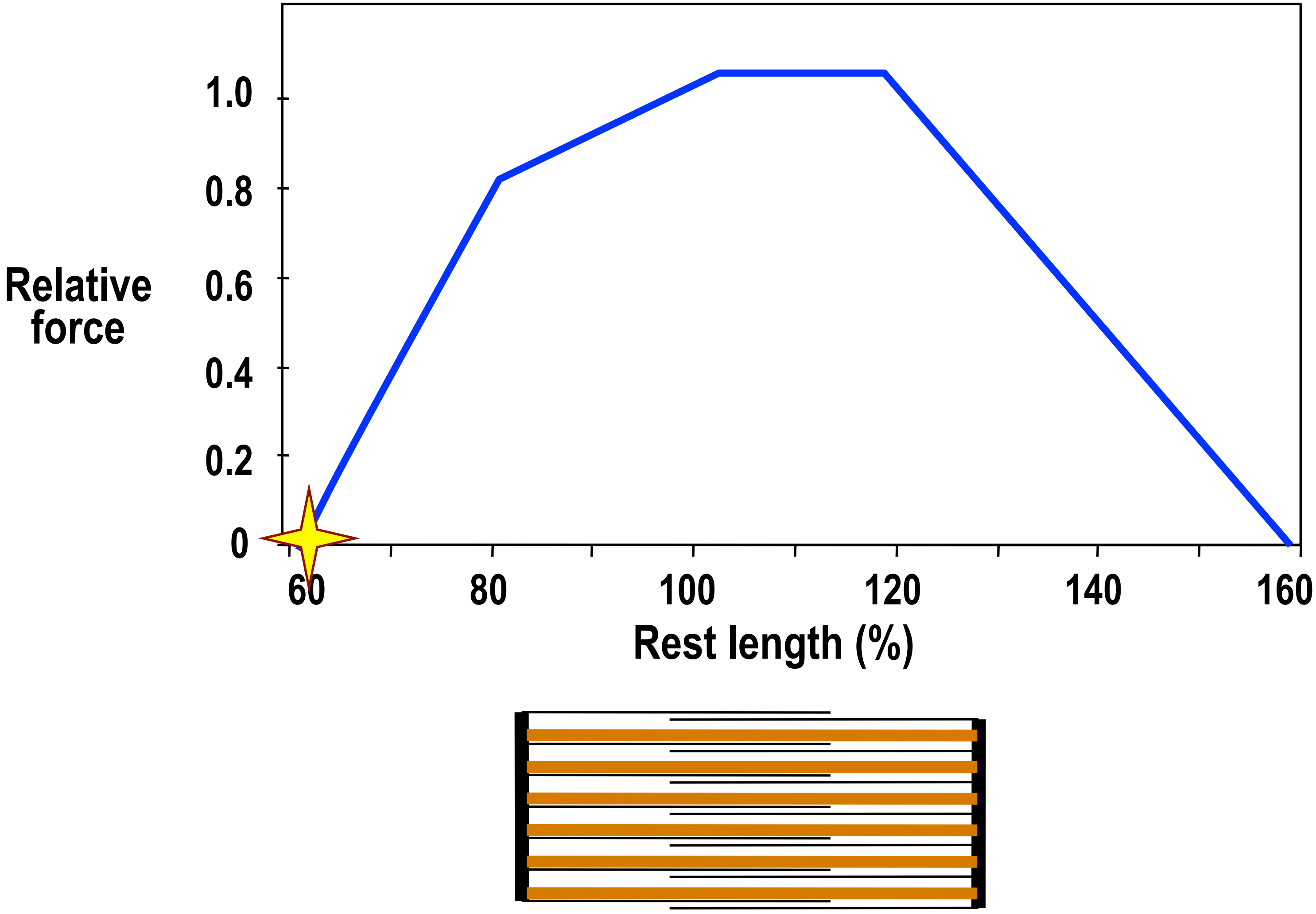


Length-tension curves continued





Length-tension curves continued



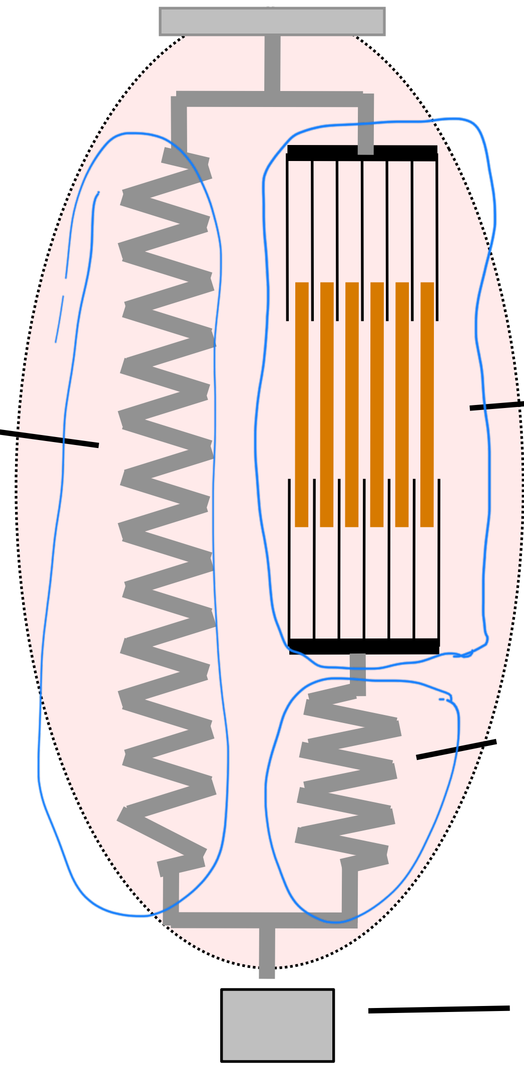
Muscle Contraction Types

1. **Isotonic contraction**
   (Gr. Iso - same, tonic - tension)
   - muscle shortens

2. **Isometric contraction**
   (Gr. Iso - same, metric - length)
   - muscle develops force

Muscle Model

Parallel Elastic Component (Membranes)

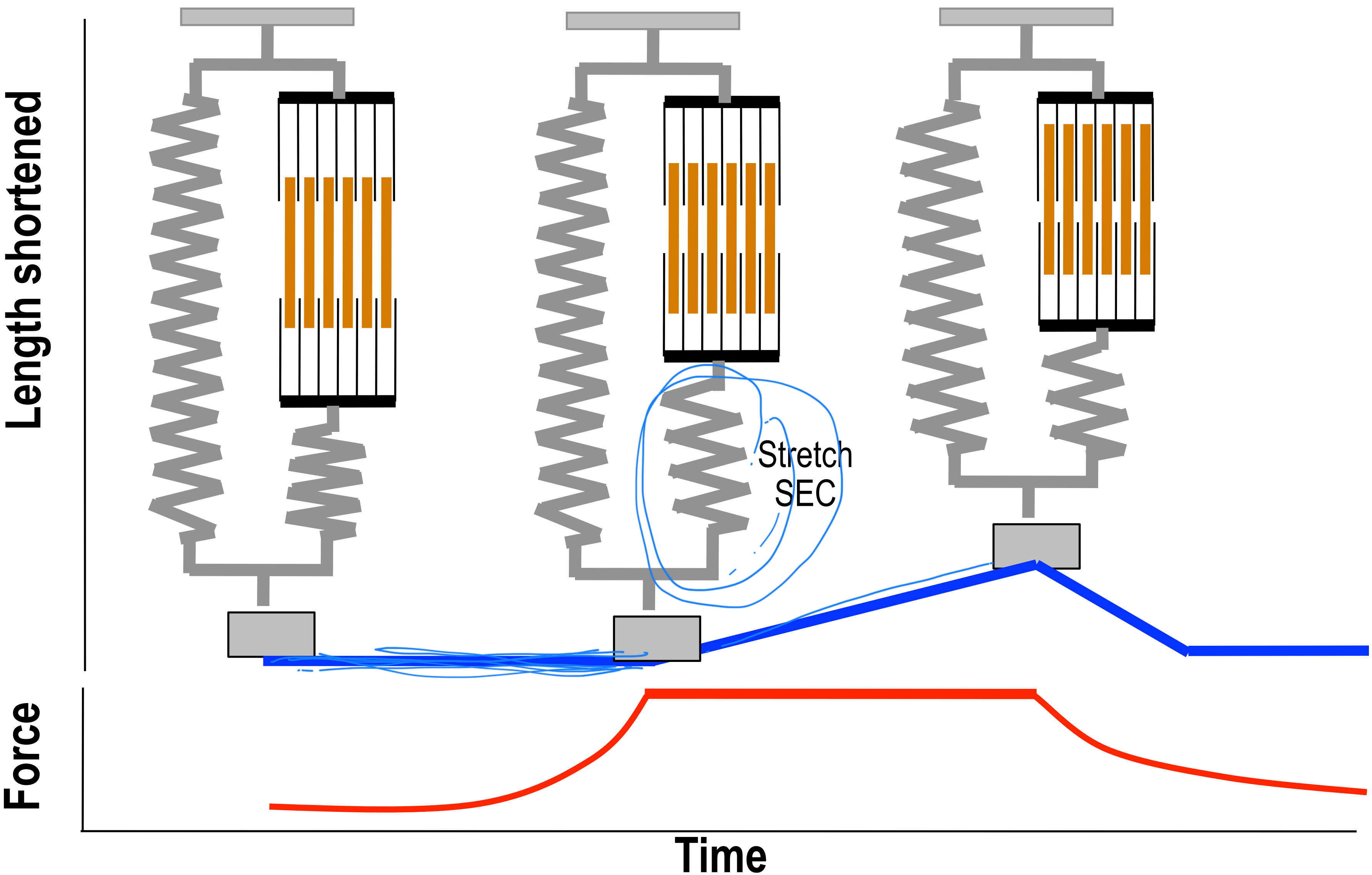


Contractile Unit (Sarcomeres)

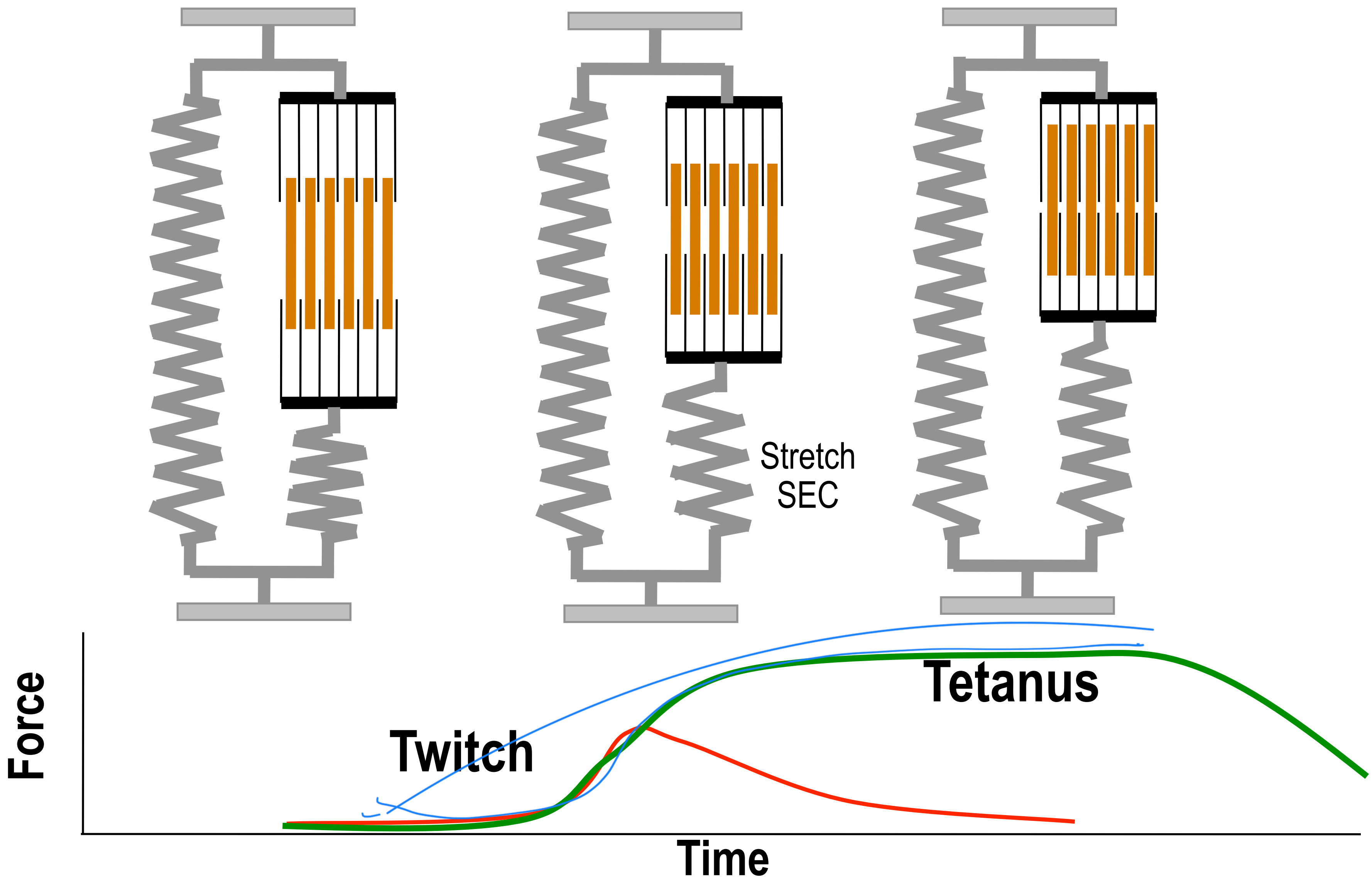
Series Elastic Component (Tendon)

Load

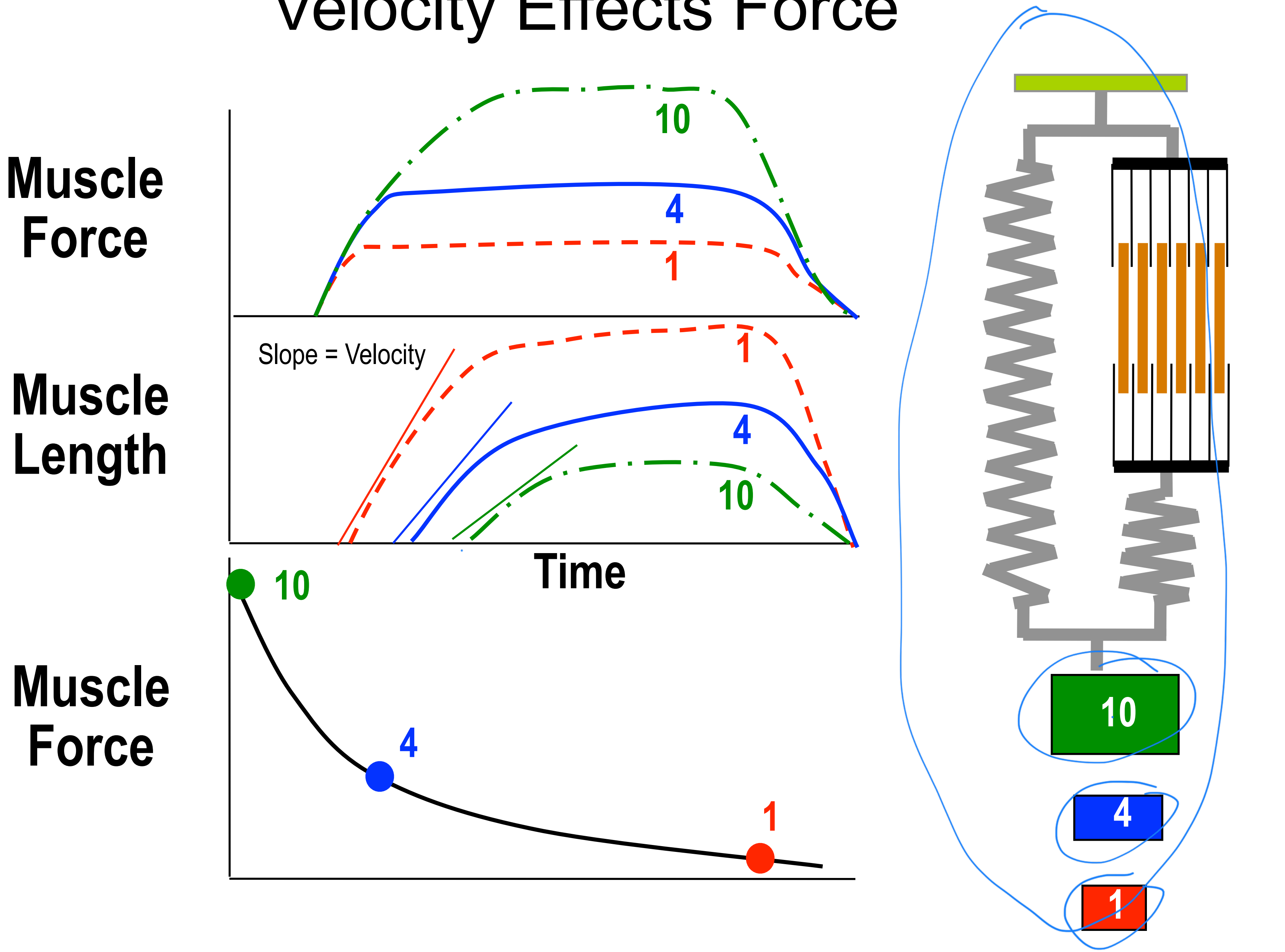
Isotonic Contraction



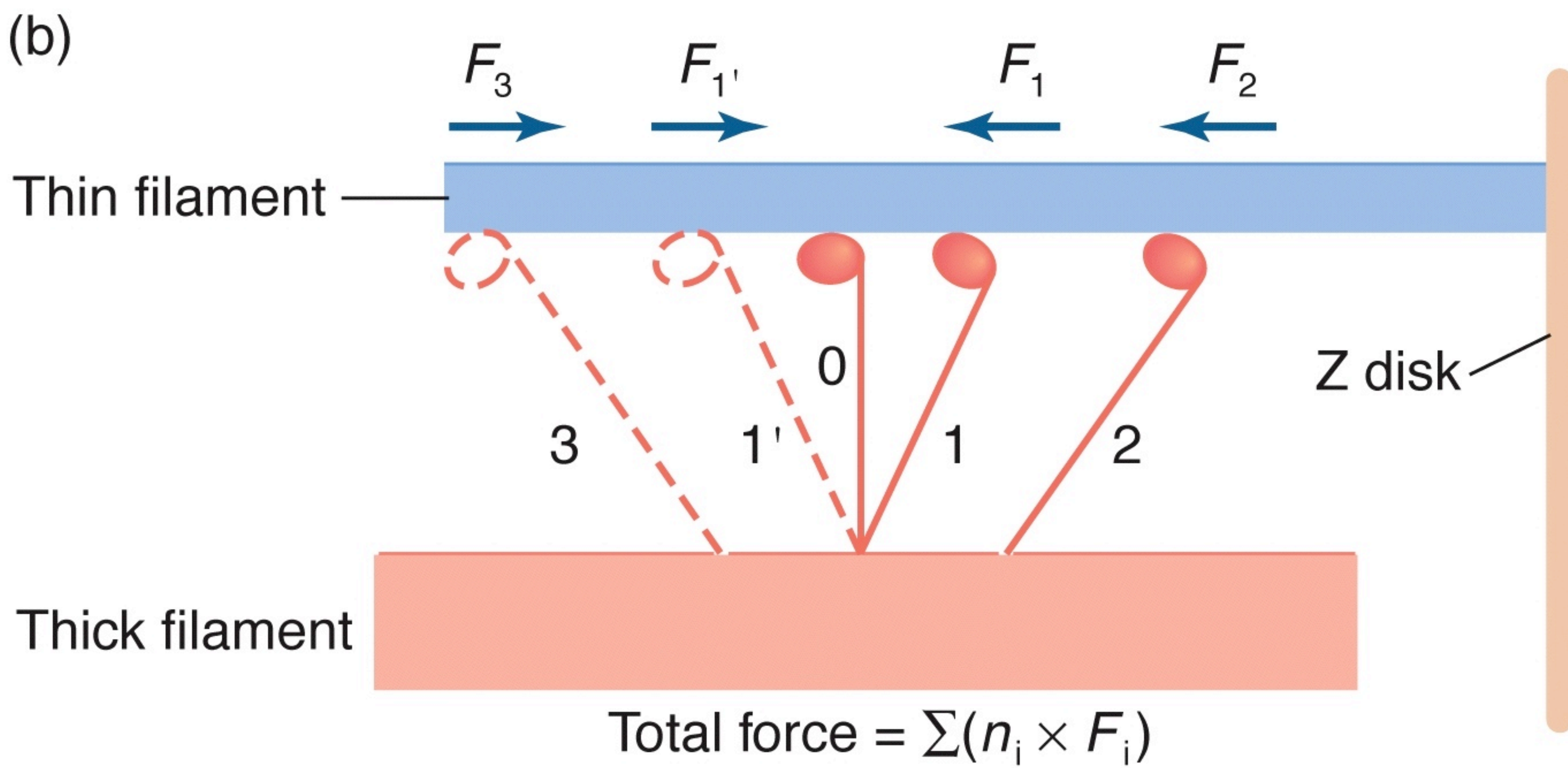
Isometric Contraction



Velocity Effects Force

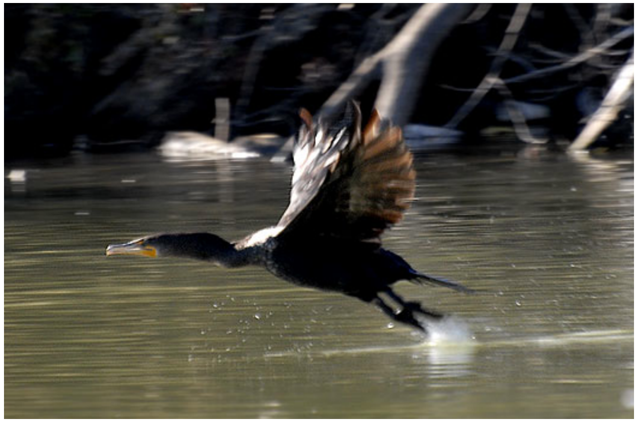


Why is force inversely related to velocity?



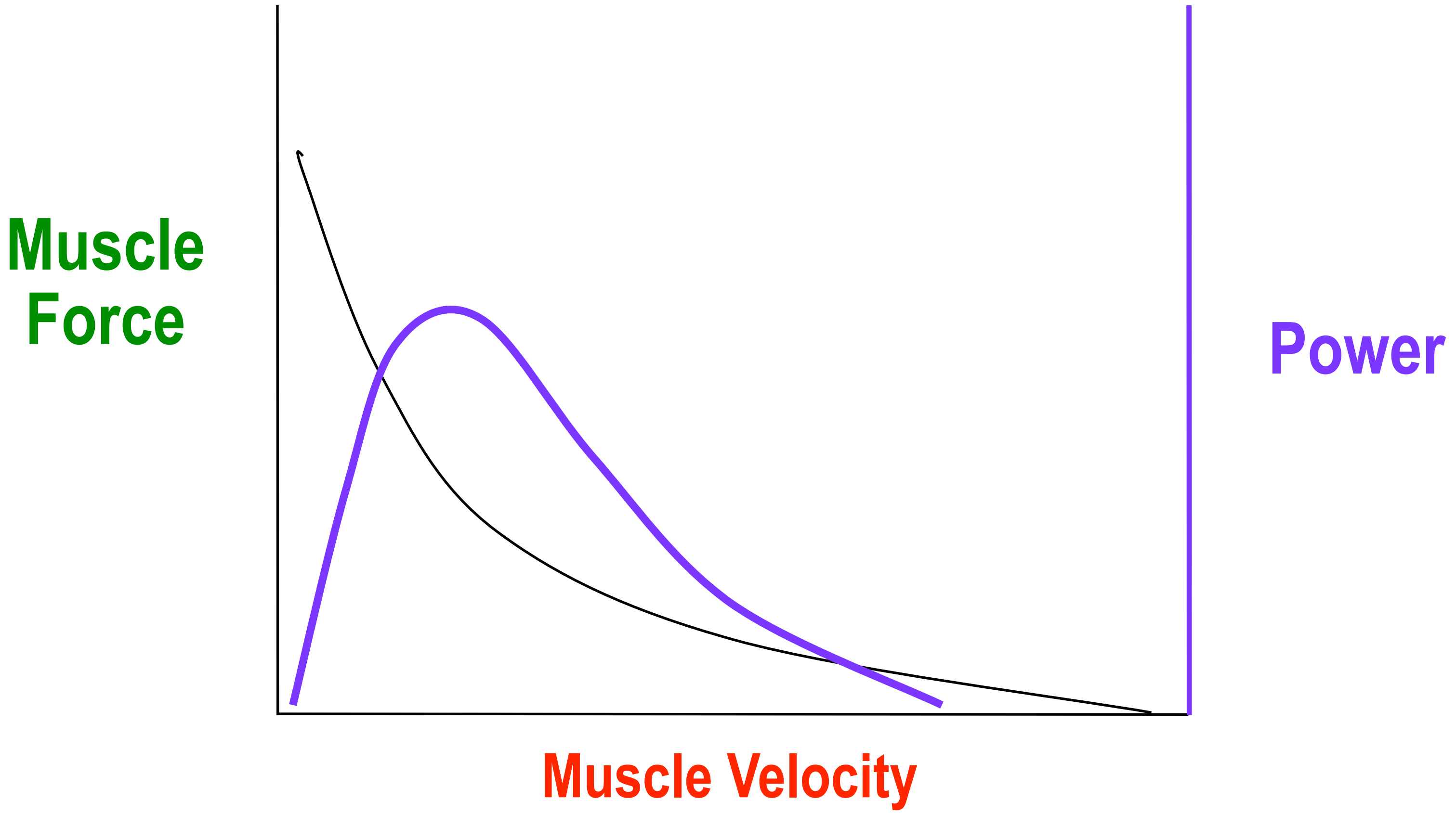
Power

- Power = work/time = (force*Δ L)/time
- Power = force * velocity (shortening)
- Power is important for many movements.
  - Jumping, flying, acceleration



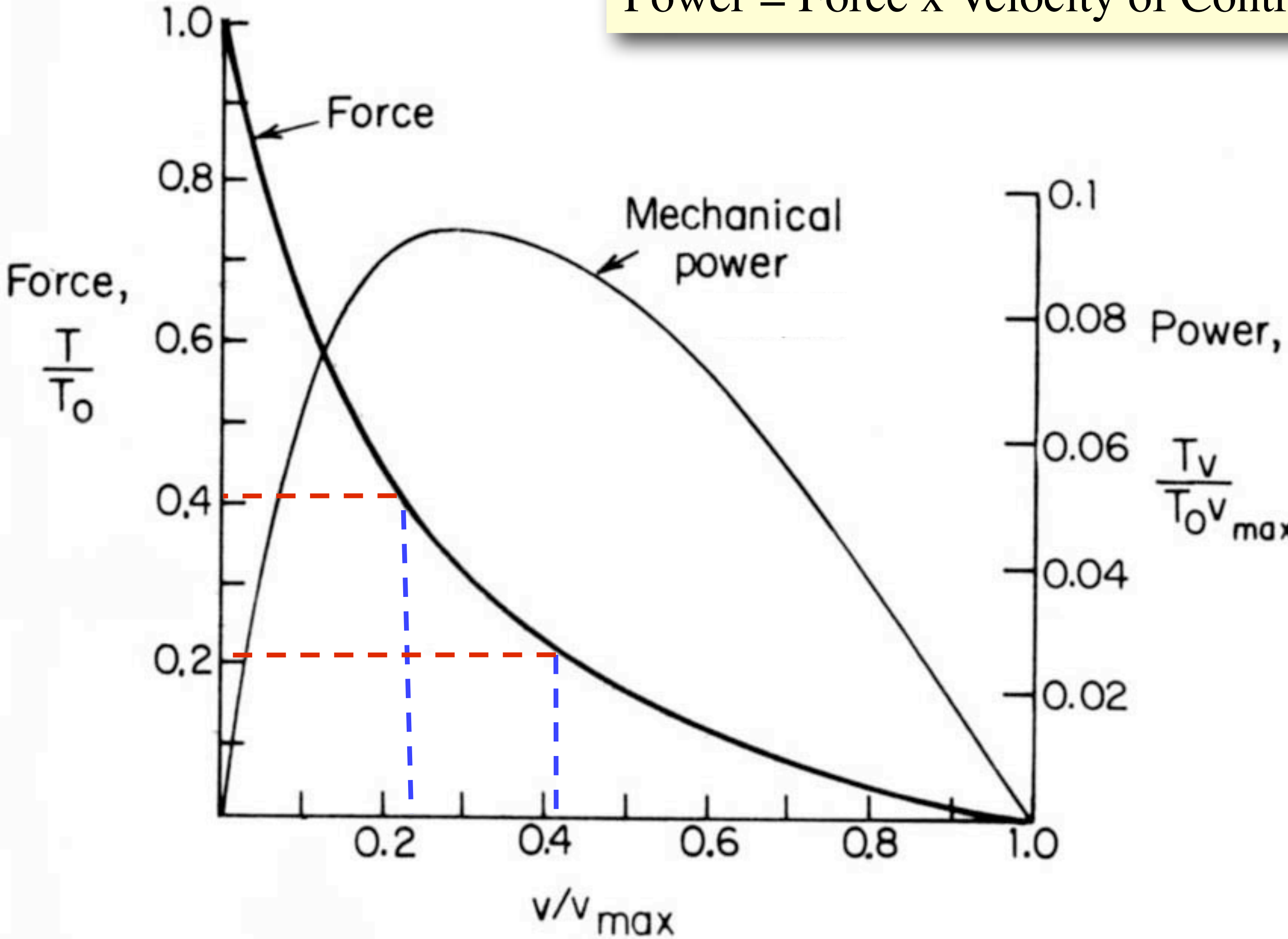
Power production

Power = Force * Velocity



Force-velocity and power-velocity relationships of muscle contraction

Power = Force x Velocity of Contraction



Determinants of Power

- ***Power is greatest at intermediate shortening velocities***
  - ***Ratio of V/V_{max} is important***
  - ***Velocity*** $\propto$ # of Sarcomeres in series
  - ***Force*** $\propto$ # of Cross-bridges in parallel

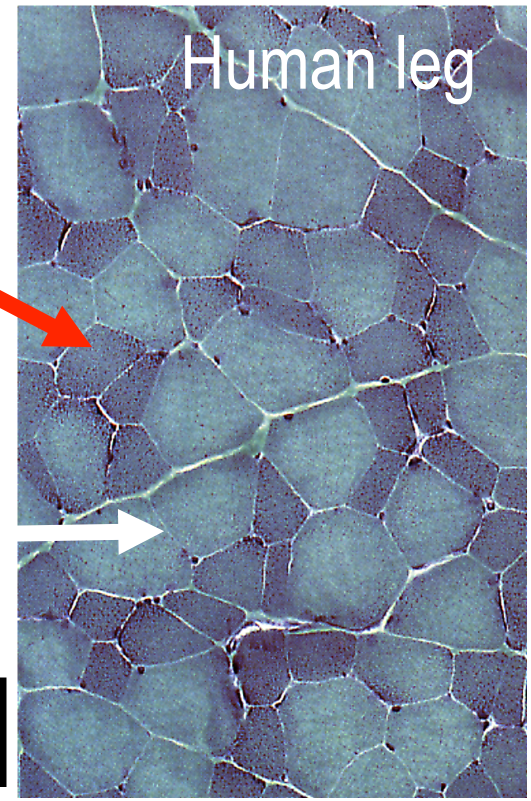
    $\propto$ cross-sectional area

Muscle Fiber Types

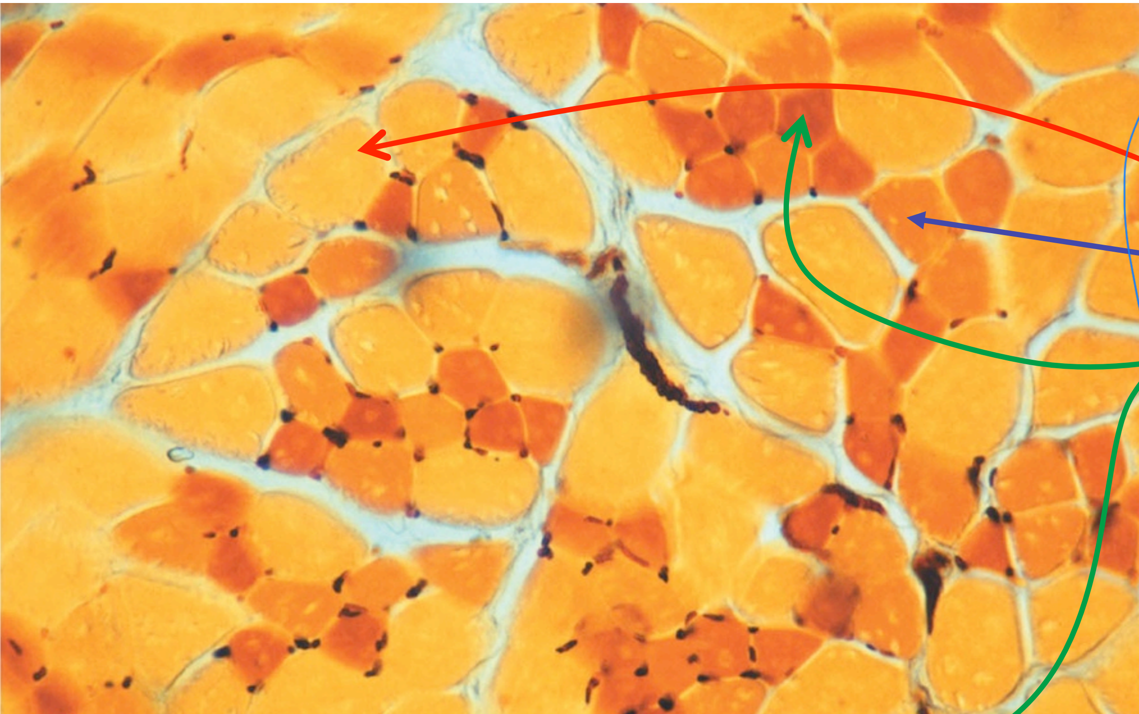
Are all muscle fibers the same?

(aerobic)
Dark meat
Red fibers

Light meat
White fibers
(anaerobic-burst)

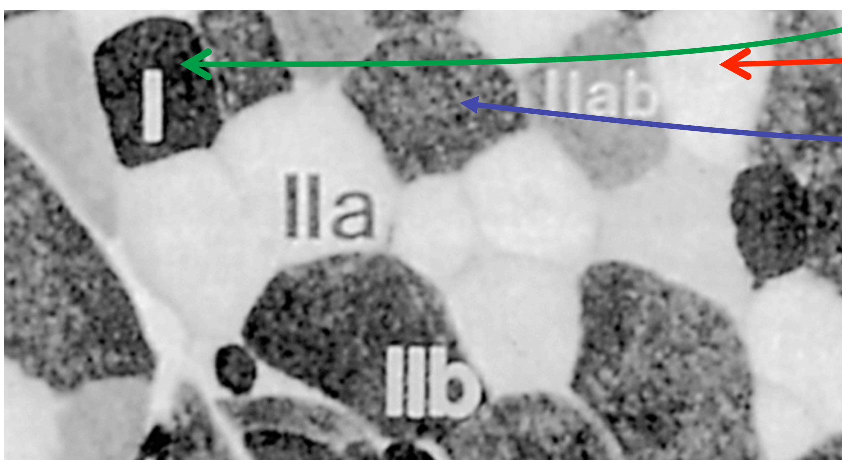


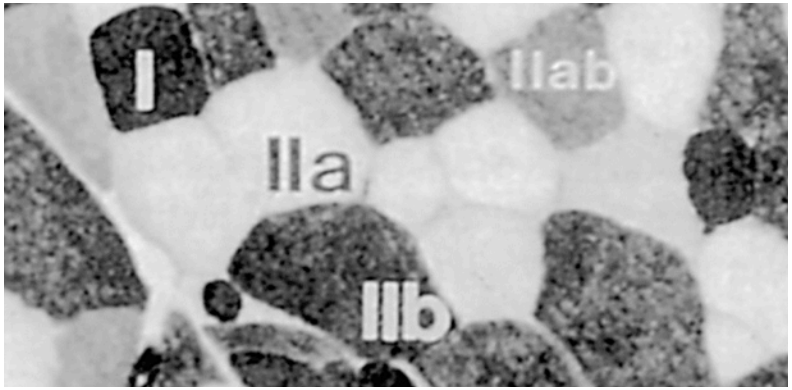
Whole muscles consist of different fiber types



Twitch: 3 types
- Fast Glycolytic
- Fast Oxidative
- Slow Oxidative

Tonic: 1 type
- Very slow, uncommon





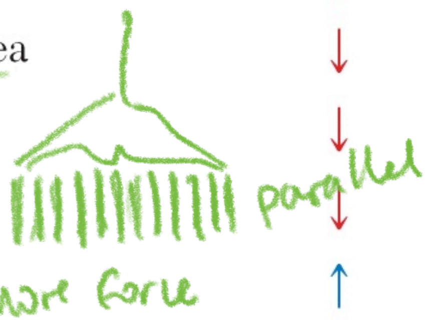
Twitch fiber characteristics

SO FOG FG

Table 10-1 Properties of twitch (phasic) fibers in mammalian skeletal muscles

Aerobic Intermediate Anaerobic

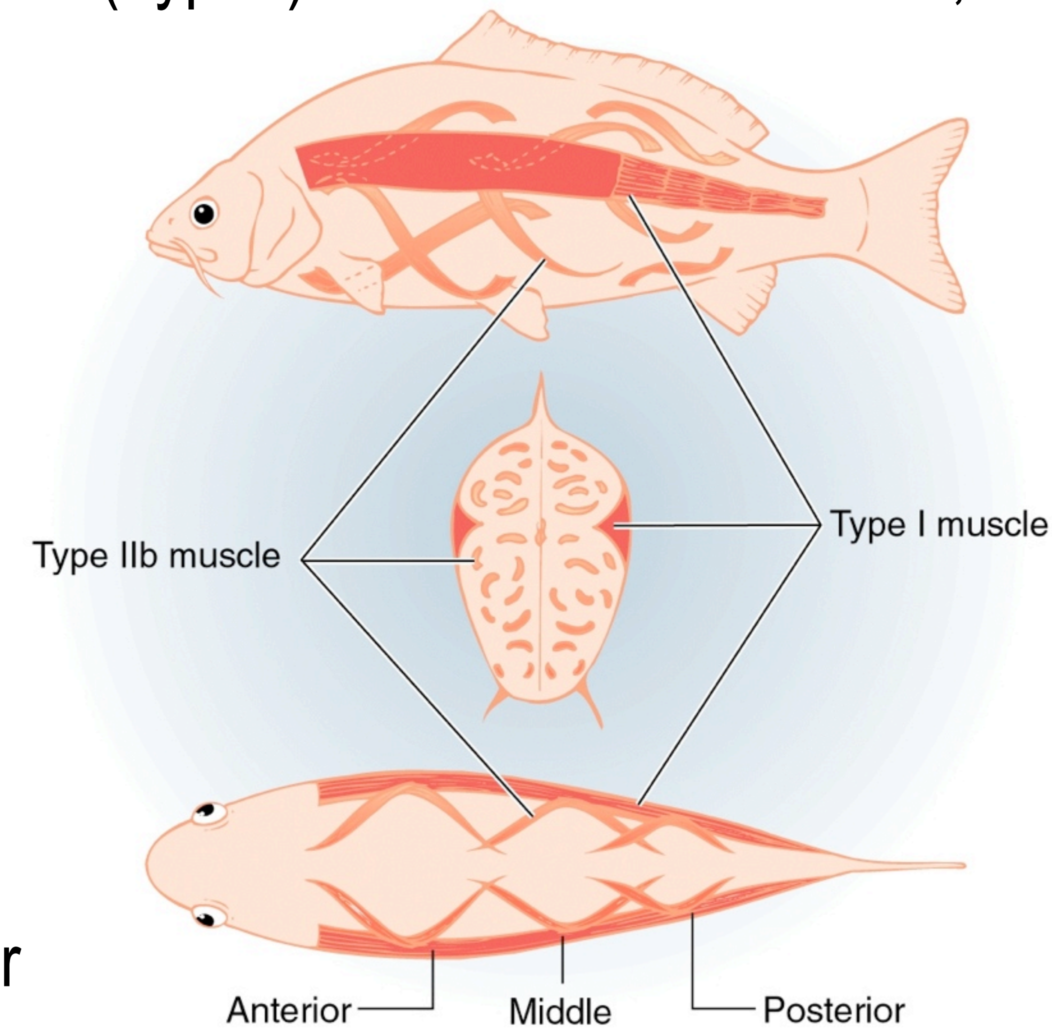
Property	Slow oxidative (type I)	Fast oxidative glycolytic (type IIa)	Fast glycolytic (type IIb)
Fiber diameter	– ↓	↔	+ ↑
Force per cross-sectional area	↓	↔	↑
Rate of contraction (V_{max})	↓	↑	↑
Myosin ATPase activity	↓	↑	↑
Resistance to fatigue	↑	↔	↓
Number of mitochondria	↑	↑	↓
Capacity for oxidative phosphorylation	↑	↑	↓
Enzymes for anaerobic glycolysis	↓	↔	↑



Source: Adapted from Sherwood, 2001. Key = ↓ Low ↔ Intermediate ↑ High

Muscle Fibers Types

Fish have red muscle fibers (Type I) on the outside for **slow**, **continuous** swimming.



Fish have white muscle fibers (Type IIb) on the inside for rapid, escape swimming.

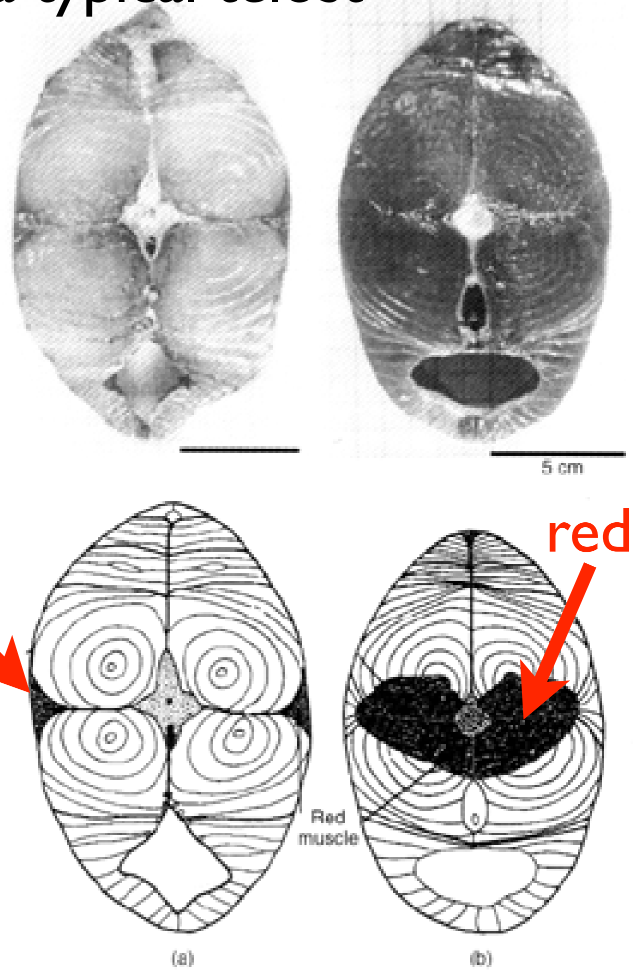
Fast (white) fibers have helical arrangement -- connecting myomeres for rapid burst

Fish Red and White Muscle Fiber Arrangement

Mackerel: a typical telost fish.

Tuna: a cruiser.

red



Biewener (2003) *Animal Locomotion*

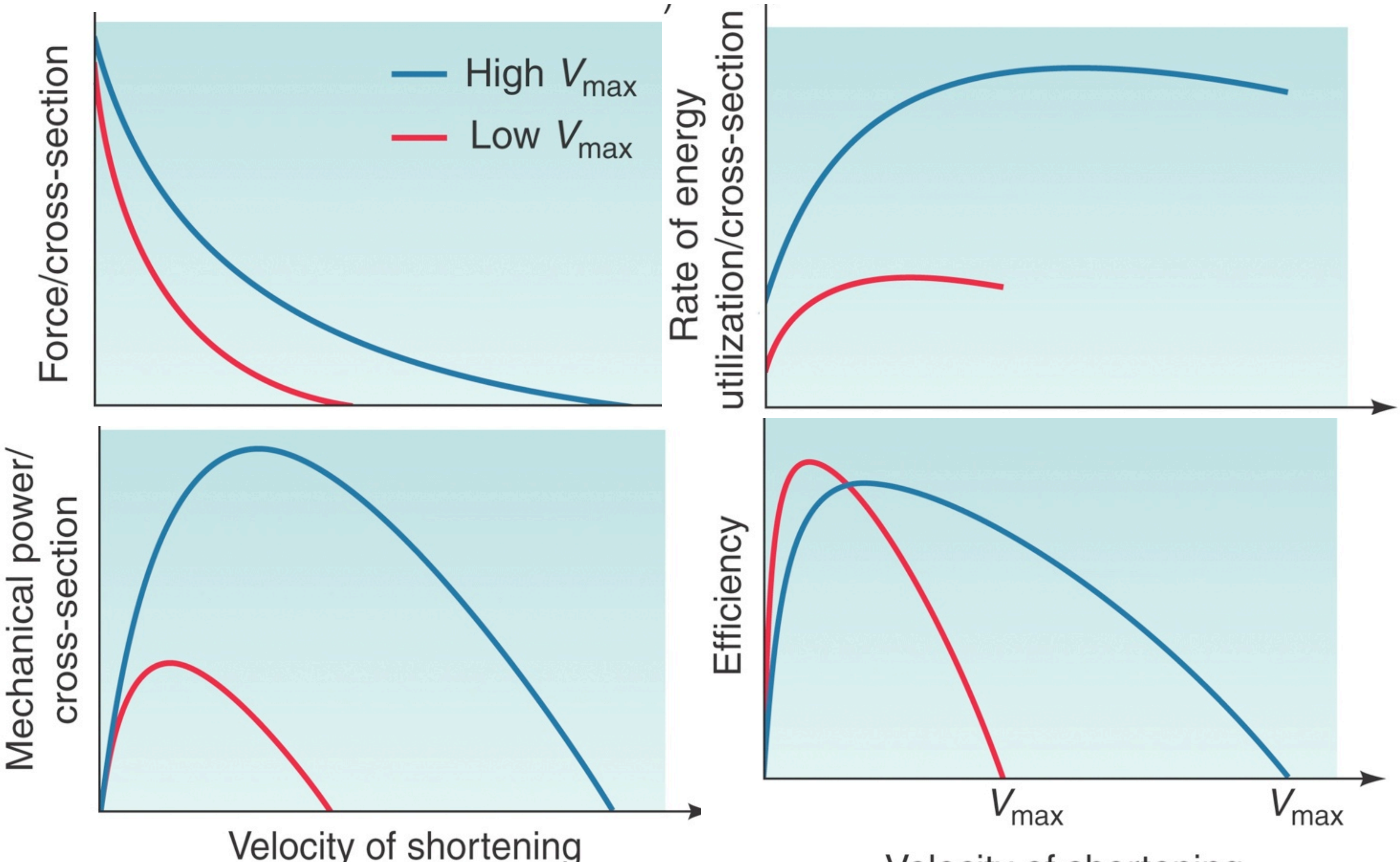
Fig. 4.14 Comparison of red and white axial muscle organization in (a) mackerel and (b) tuna (two scombrid fishes). In most fish, such as the mackerel, the red muscle represents a limited portion of the myotomal muscle and is located just beneath the skin lateral to the white muscle. In tuna and other fish which warm their red muscle, the red muscle is more extensive and lies deep to much of the white muscle. Counter-current heat exchange keeps the red muscle warmer than the water and the rest of the fish (some fish also maintain elevated brain and eye temperatures). (Reproduced from Westneat and Wainwright (2001), with permission from Academic Press.)

Slow-twitch (red) fibers are oxidative (aerobic), have rich blood supply, contract slowly, but do not fatigue or go into oxygen debt.

Fast-twitch (white) fibers are glycolytic (anerobic), optimized for fast bursts of speed.

Tunas keep their slow-twitch muscles warm by having them arranged internally to fast-twitch muscles.

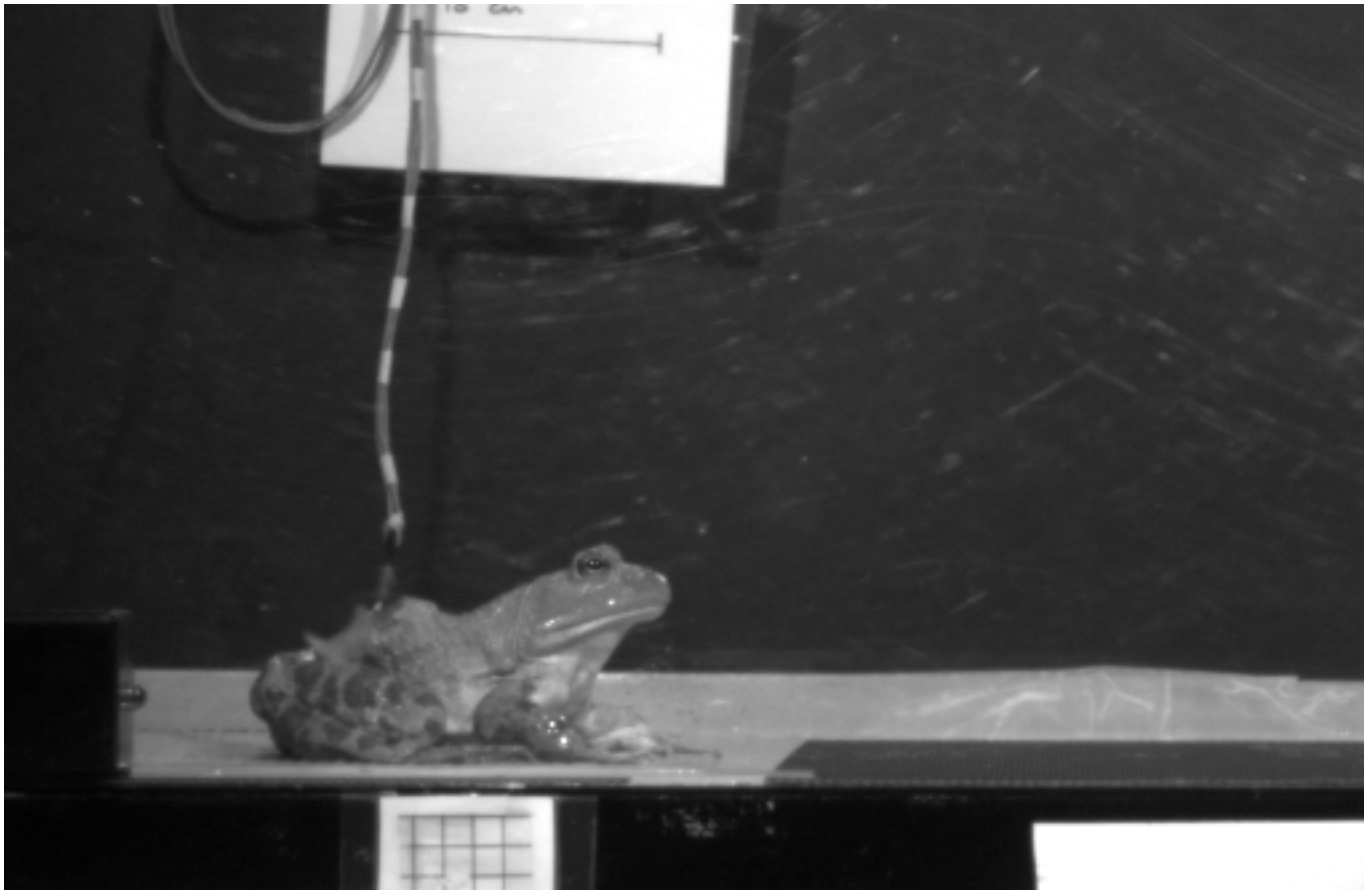
Fast vs. Slow Twitch Fibers



Adaptation of muscle function

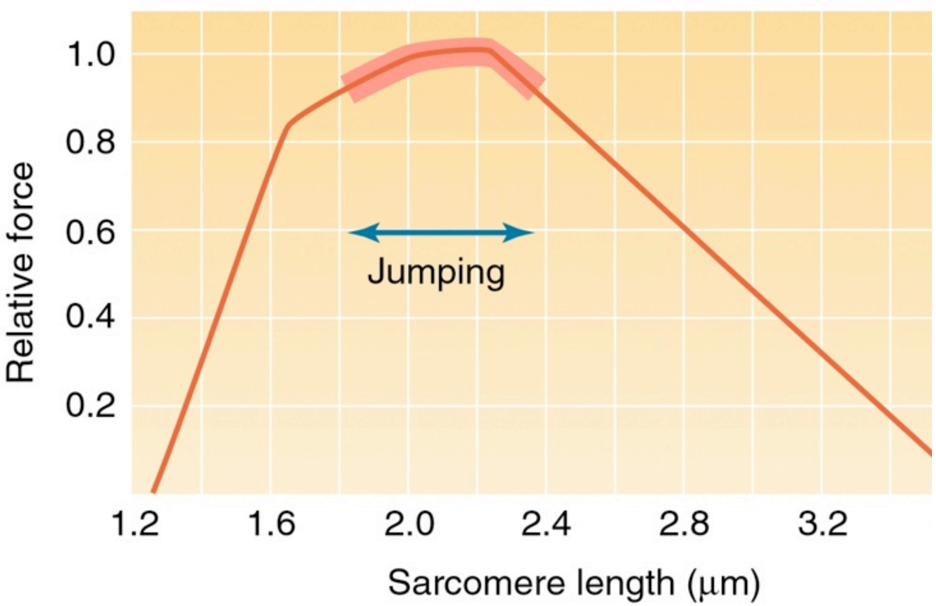
- Velocity of shortening (V/V_{max})
- Timing and duration of muscle activity
- Muscle size
- Fiber types
- Arrangement of fiber types
- Temperature
- Overlap of thick and thin filaments
- Muscle attachment

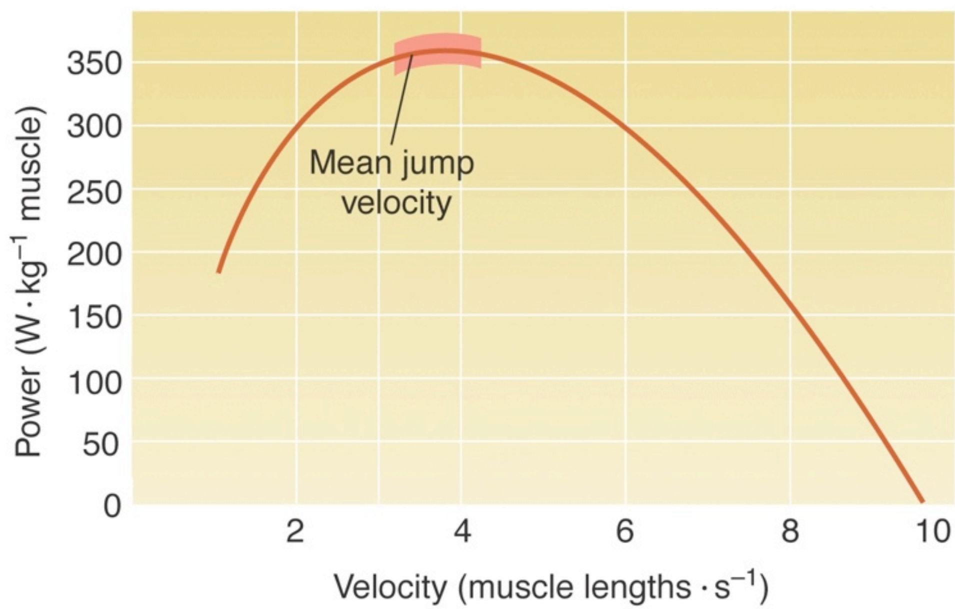
Adaptation for Power: Jumping Frogs



Adaptation for Power: Jumping Frogs

- Frogs move rapidly
  - from crouched to extended position in 50-100 ms
- Power produced = jump height
- Frogs jump when sarcomere length and muscle contraction velocity are optimal





Muscle Design takes into account Power, speed, & energetics.

- A wide variety of motor tasks are required by muscle.
- Some require high speed contractions, powerful contraction, repetitive sustained contraction, or forceful sustained contractions.
- By altering the traits and design of fibers/ muscle a muscle can be specialized for a specific function.
- Energetics are also important (faster contracting muscles use ATP faster).

Muscle adaptation for non-locomotory function

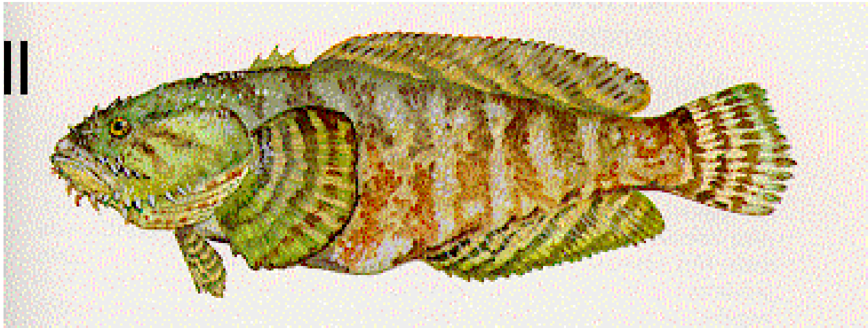
- Sound production
  - Rattlesnake rattle, Toadfish swimbladder
- Electrical potential generation
  - Electric Eels
- Heat generation
  - Ocular muscles in billfishes

Tradeoffs: Increased density of energy production, decreased density of contractile apparatus

Sound Production: Rattlesnakes

- Rattlesnake “rattler” can have sustained vibrations of over 90 per second (90Hz) for hours
- Rattler shaker muscles have reduced contractile apparati (low force required) and higher energetic components

Sound Production: Toadfish



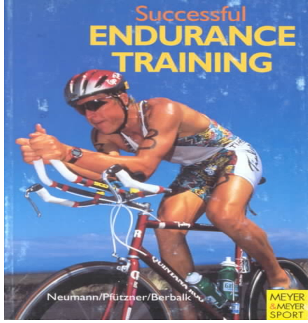
- Toadfish makes a mating call 10-12 times per minute for hours on end
- Sound is produced by rapid oscillation of muscles surrounding the fishes swim bladder (100-200 Hz)
- However, toadfish locomotory muscle is very slow (1-2 Hz)
- Difference: Ca^{2+} kinetics, muscle morphology
  - Incr. Ca^{2+} channels
  - Incr. troponin
  - Decr. Diffusion distances

Acclimation/Acclimatization

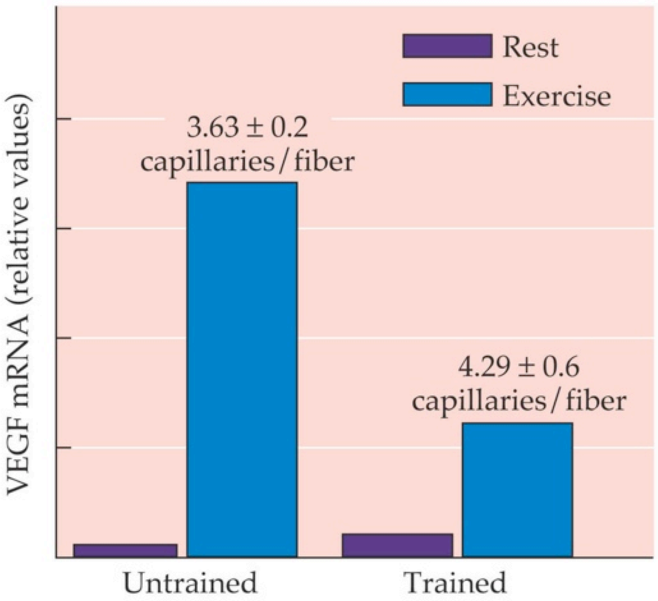
- Changes in muscle within an organisms lifetime:
  - Training
  - Atrophy
- Types of training:
  - Endurance
    - oxidative
  - Resistance
    - anaerobic

Muscles don't change length or increase number of fibers

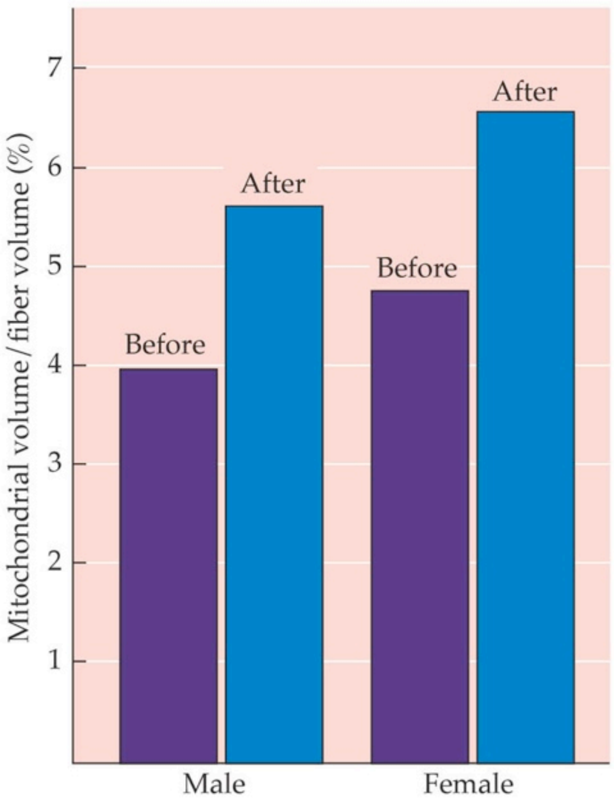
Endurance Training:



- Increases Vascularization



- Increases oxidative capacity



Resistance Training

- Increases Muscle Volume
  - # myofibrils per muscle cell

    (myofibril bundles increase within muscle fiber cell --

    # muscle fibers don't change)

- Changes Fiber Composition