Chapter 11.3

Isotonic VS Isometric Contractions

Length Tension Relationships

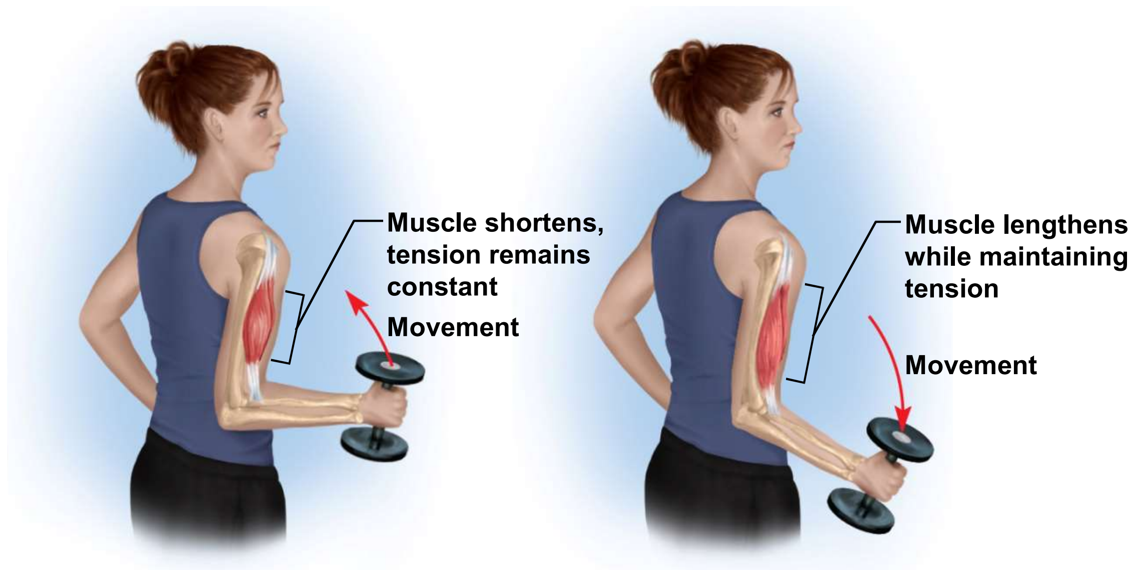
Whole Muscle Behavior

Slow VS Fast Muscle Fibers

Muscle Conditioning

- **Isometric Muscle Contractions**
  - muscle contracts without the muscle shortening
  - muscle is producing tension while resistance causes it to stay the same length
  - this can be a prelude to movement while tension is absorbed by the elastic component of muscle // as tension exceeds resistance then muscle shortens
  - important in postural muscle function and antagonistic muscle joint stabilization

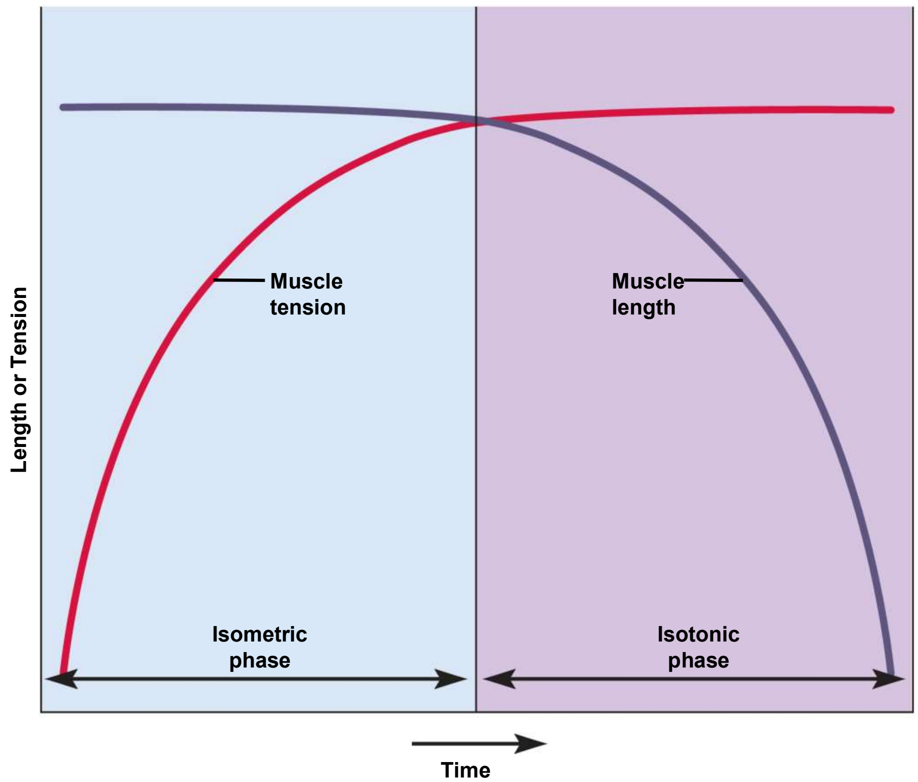
Isotonic Contractions



Isotonic concentric contraction   Isotonic eccentric contraction

- Isotonic Muscle Contractions // muscle changes length (i.e. shortens or lengthens) as tension within muscle now exceeds resistance
  - <u>Isotonic concentric contraction</u> – muscle shortens while maintains tension
  - <u>Isotonic eccentric contraction</u> – muscle lengthens as it maintains tension

Isometric and Isotonic Phases of Contraction



- beginning of contraction = **isometric phase**
  - muscle tension rises but muscle does not shorten
  - removing elastic component of the muscle & building tension equal to the load

- when tension overcomes the resistance of the load // tension now levels off

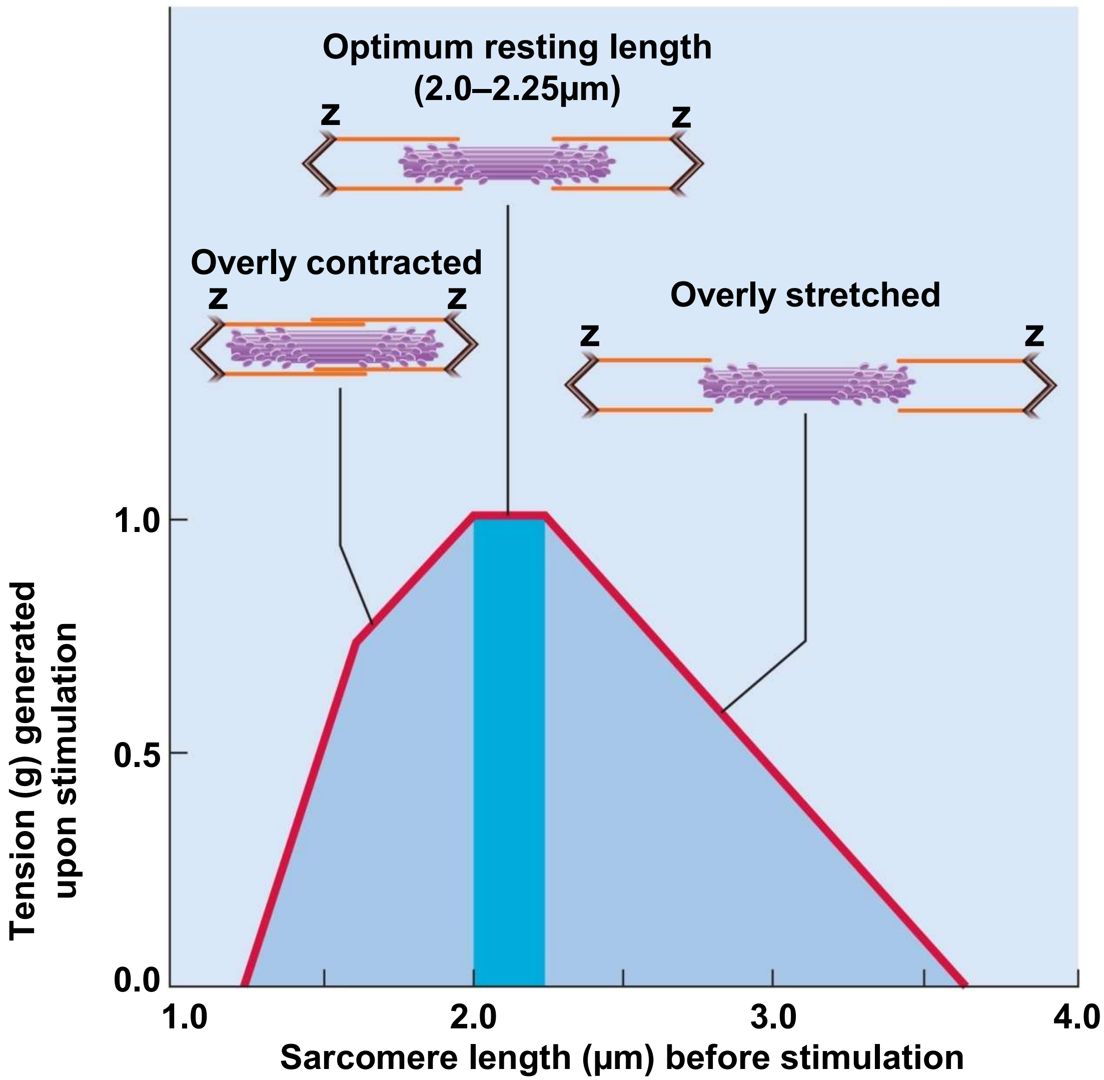
- muscle now begins to shorten, the load starts to move, and now tension does not change
  = **isotonic contraction**

Length Tension Relationship

Length-Tension Relationship

- This is the relationship between the length of the sarcomere (i.e. stretched VS compressed) and the amount of tension the muscle can generate
  - depends on how stretched or contracted “the sarcomeres” are before muscle is stimulated
  - maximum tension requires proper distance between Z discs
- If sarcomeres are contracted at rest – then weak tension results /// why? - thick filament's ends are too close to Z discs and they can’t slide
- If sarcomeres too stretched before stimulated – then a weak tension results /// why? - little overlap of thin and thick does not allow for very many cross bridges to form

Length-Tension Relationship



Length-Tension Relationship

- optimum resting length – produces greatest force when muscle contracts

- muscle tone

  - central nervous system continually monitors and adjusts the length of the resting skeletal muscles

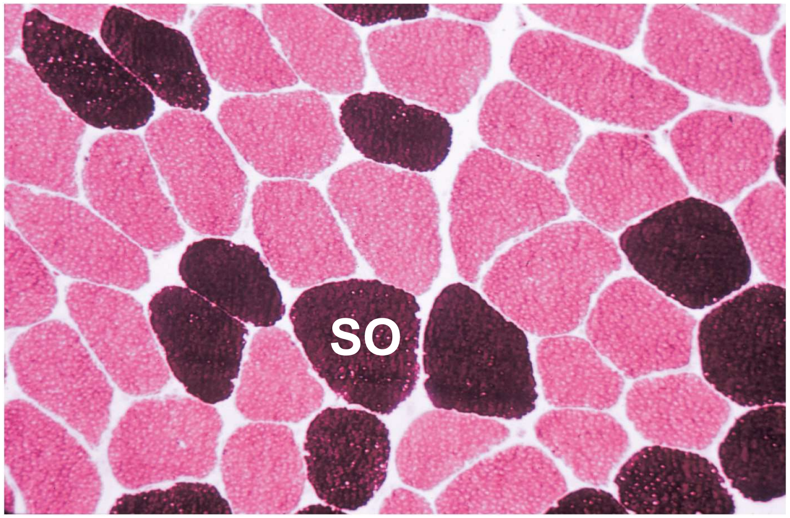
  - maintains a state of partial contraction called muscle tone

  - This maintains optimum length and makes the muscles ideally ready for action /// maintains proper length-tension balance

Different Functions of Muscle Fibers (Slow VS Fast)

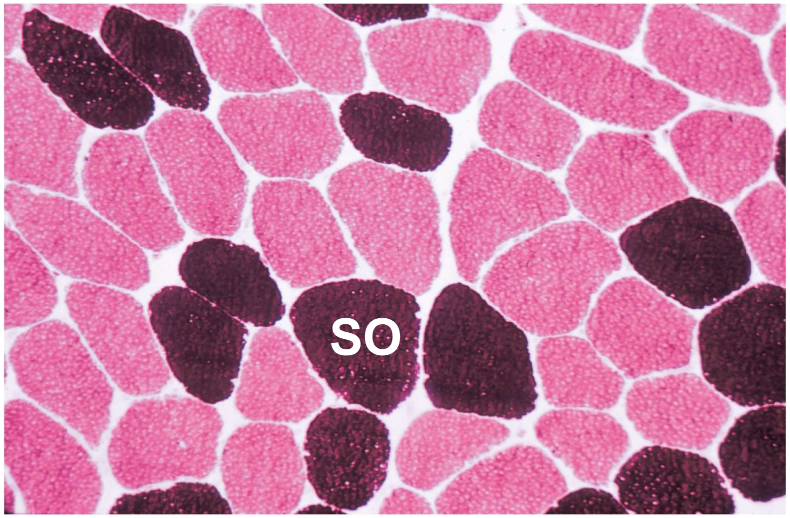
Physiological Classes of Muscle Fibers

- ratio of different fiber types (SO vs FG) have genetic predisposition – born sprinter vs born marathon runner
  - muscles differ in fiber types – gastrocnemius // predominantly FG for quick movements (jumping)
  - soleus is predominantly SO // used for endurance (jogging)



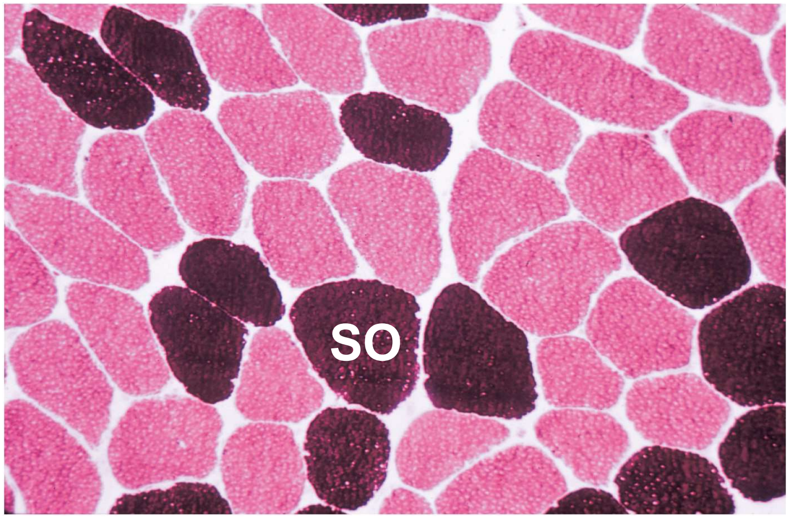
Physiological Classes of Muscle Fibers

- slow oxidative (SO)
  - slow-twitch, deeper red color because of greater density of capillaries, or type I fibers
  - abundant mitochondria, myoglobin and capillaries - deep red color
  - adapted for aerobic respiration and fatigue resistance
  - relative long twitch lasting about 100 msec
  - soleus of calf and postural muscles of the back

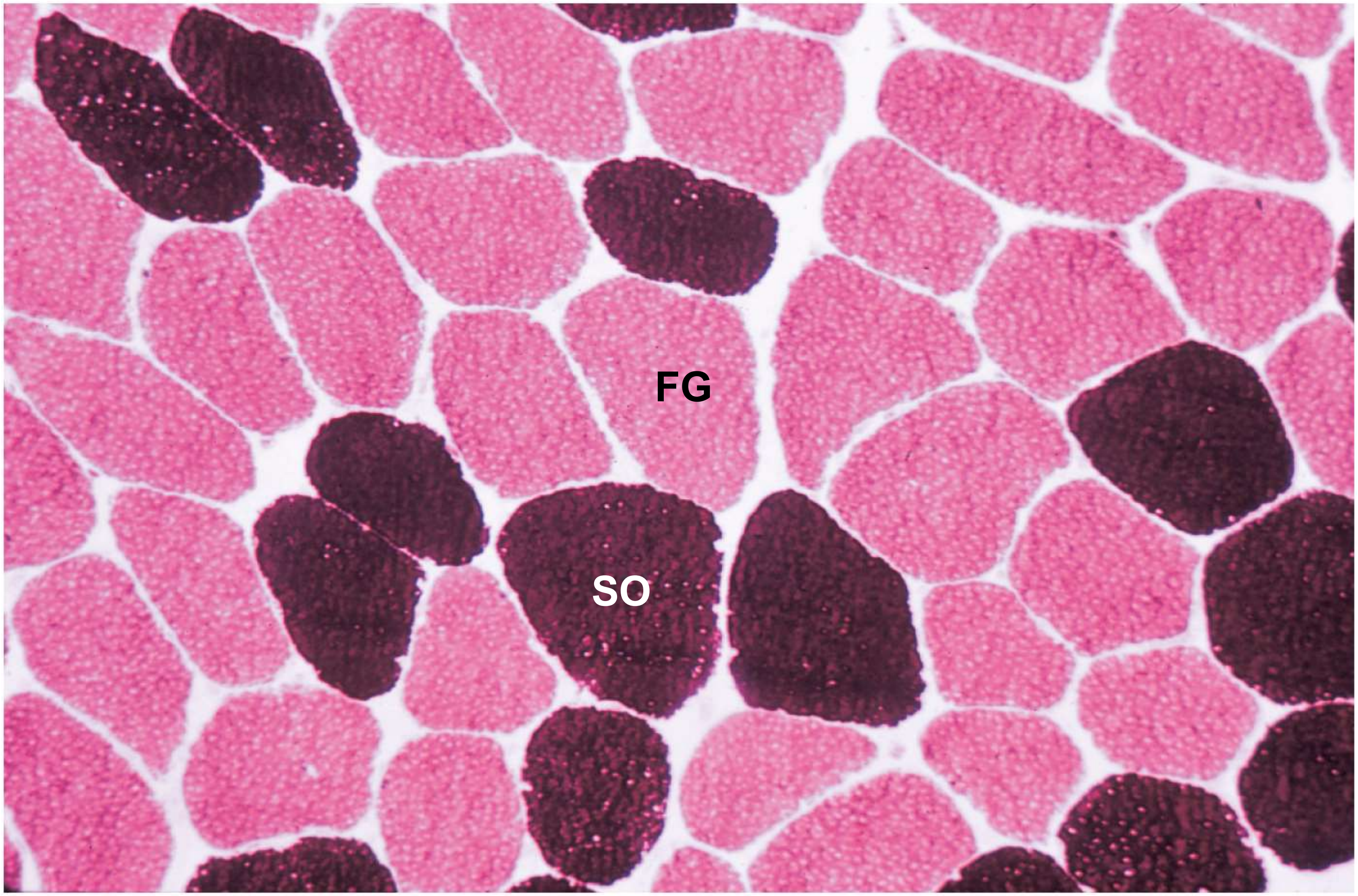


Physiological Classes of Muscle Fibers

- fast glycolytic (FG)
  - fast-twitch, white, or type II fibers
  - fibers are well adapted for quick responses, but not for fatigue resistance
  - rich in enzymes of phosphagen and glycogen-lactic acid systems generate lactic acid causing fatigue
  - poor in mitochondria, myoglobin, and blood capillaries which gives pale appearance
  - SR releases & reabsorbs Ca^{+2} quickly so contractions are quicker (7.5 msec/twitch)
  - extrinsic eye muscles, gastrocnemius and biceps brachii



FG and SO Muscle Fibers



Strength and Conditioning

- muscles can generate more tension than the bones and tendons can withstand
- muscular strength depends on primarily on **muscle size**
- a muscle can exert a tension of 3 or 4 kg / cm^2 of cross-sectional area
- Factors affecting strength of muscle contraction
  - **fascicle arrangement ///** pennate are stronger than parallel, and parallel stronger than circular
  - **size of motor units ///** larger the motor unit the stronger the contraction

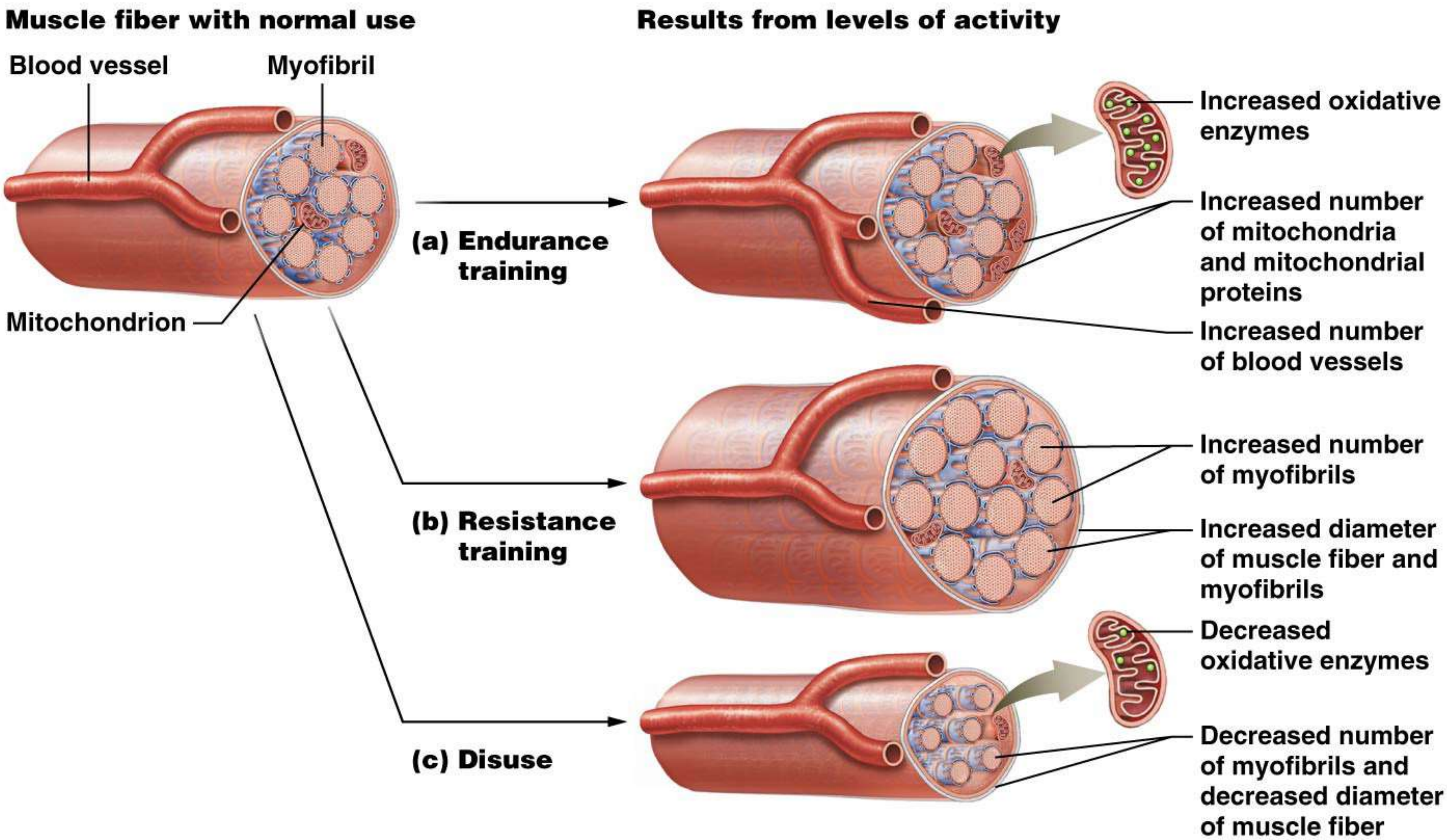
Strength and Conditioning

- multiple motor unit summation – recruitment //// when stronger contraction is required, the nervous system activates more motor units
- temporal summation
  - nerve impulses usually arrive at a muscle in a series of closely spaced action potentials
  - the greater the frequency of stimulation, the more strongly a muscle contracts
- length – tension relationship //// a muscle resting at optimal length is prepared to contract more forcefully than a muscle that is excessively contracted or stretched
- Fatigue /// fatigued muscles contract more weakly than rested muscles

Strength and Conditioning

- **resistance training** (weight lifting)
  - contraction of a muscles against a load that resist movement
  - a few minutes of resistance exercise a few times a week is enough to stimulate muscle growth
  - growth is from cellular enlargement
  - muscle fibers synthesize more myofilaments and myofibrils and grow thicker
- **endurance training** (aerobic exercise)
  - improves fatigue resistant muscles
  - slow twitch fibers produce more mitochondria, glycogen, and acquire a greater density of blood capillaries
  - improves skeletal strength
  - increases the red blood cell count and oxygen transport capacity of the blood
  - enhances the function of the cardiovascular, respiratory, and nervous systems

Adaptive changes of muscle fibers due to training and disuse.



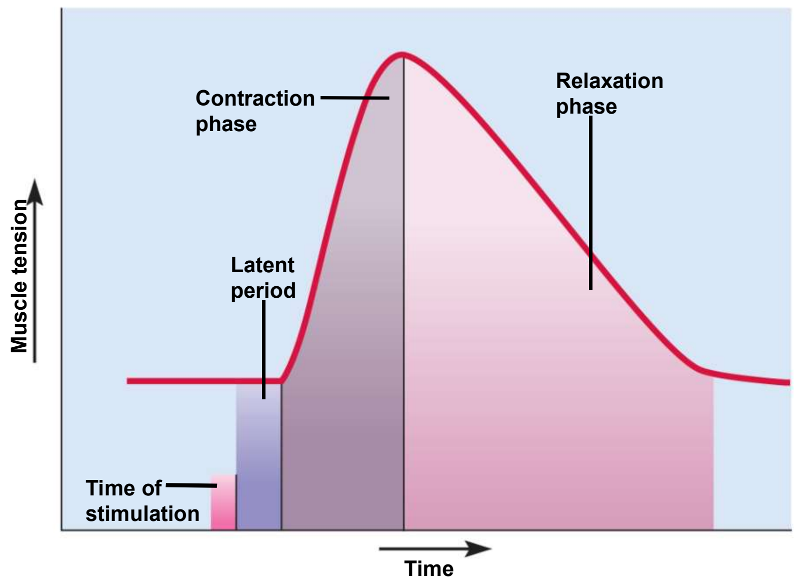
Note: R. training also increase CT (strength of fiber membranes, tendons, periosteum, and bone matrix)

Whole Muscle Behavior

Behavior of Whole Muscles

- This is the response of a muscle to a weak electrical stimulus seen in frog gastrocnemius - sciatic nerve preparation

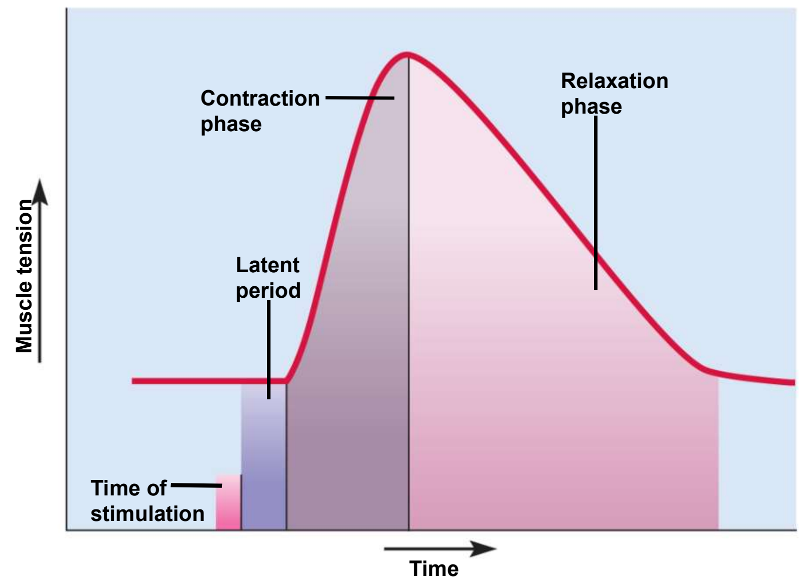
- **myogram** – a chart of the timing and strength of a muscle's contraction

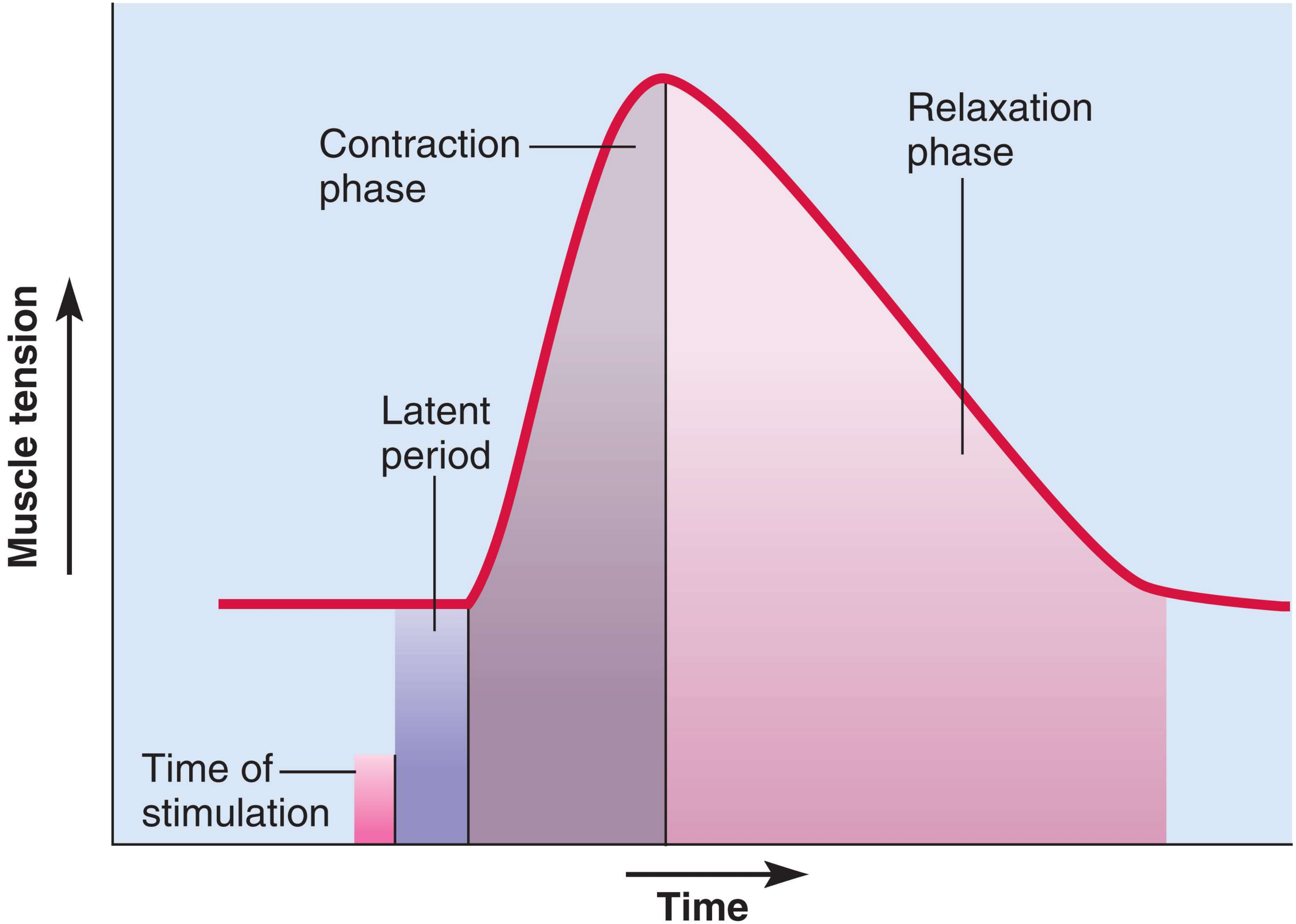


Behavior of Whole Muscles

Weak, subthreshold electrical stimulus causes no contraction

- **threshold**
  - the minimum voltage necessary to generate an action potential in the muscle fiber
  - produces a contraction called a **twitch** – a quick cycle of contraction and relaxation when stimulus is at threshold or higher



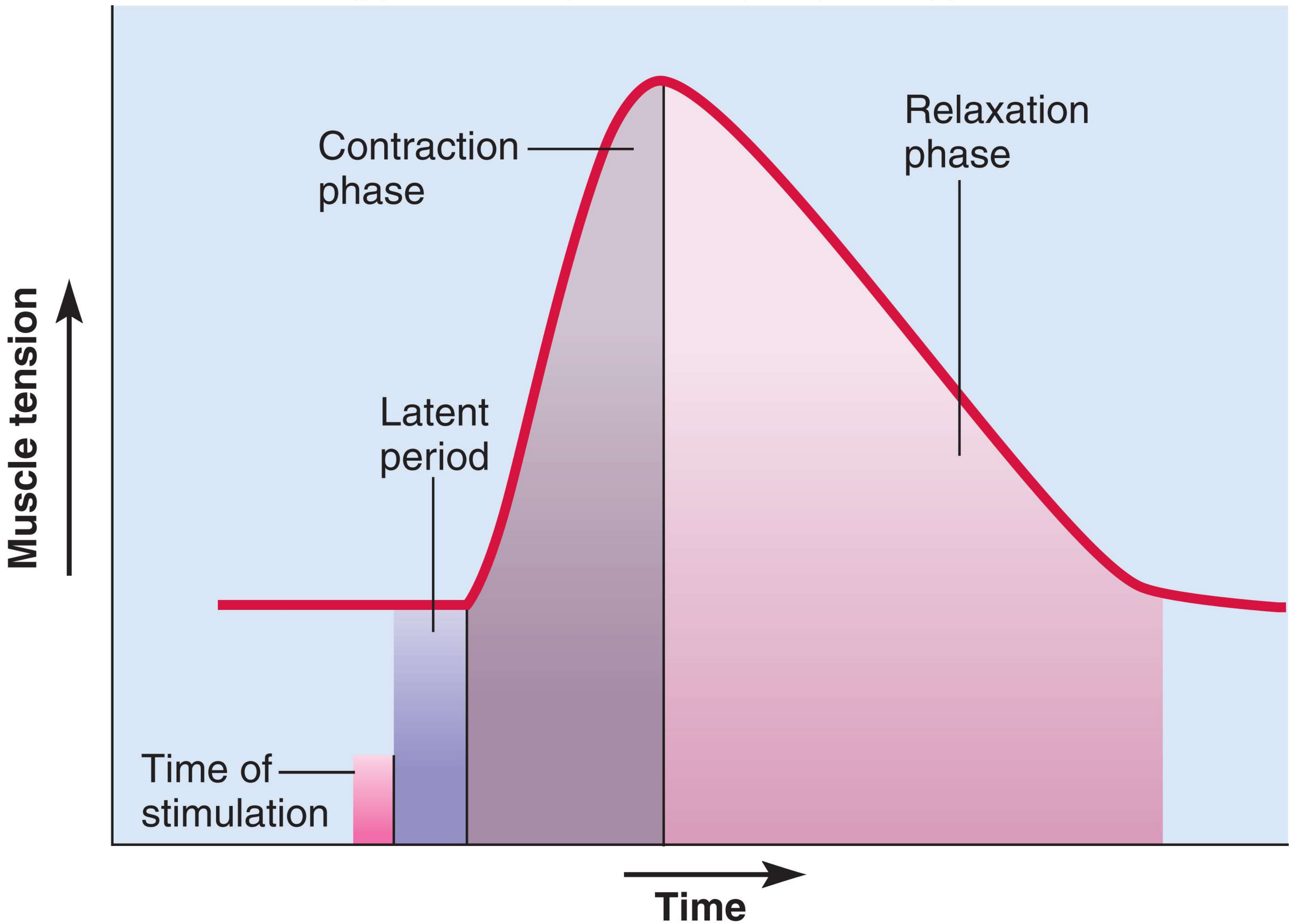

Contraction phase
Relaxation phase
Latent period
Muscle tension
Time of stimulation
Time

Phases of a Twitch Contraction

- latent period
  - 2 msec delay between the onset of stimulus and onset of twitch response
  - time required for excitation, excitation-contraction coupling and tensing of elastic components of the muscle
  - internal tension – force generated during latent period and no shortening of the muscle occurs

Phases of a Twitch Contraction

- contraction phase
  - phase in which filaments slide and the muscle shortens
  - once elastic components are taut, muscle begins to produce external tension – in muscle that moves a load
  - short-lived phase
- relaxation phase
  - SR quickly reabsorbs Ca^{+2}
  - myosin releases the thin filaments and tension declines
  - muscle returns to resting length
  - entire twitch lasts from 7 to 100 msec


Contraction phase
Relaxation phase
Latent period
Time of stimulation
Muscle tension
Time

Why Twitches Vary in Strength

- Stimulus frequency // stimuli arriving closer together produce stronger twitches

- Concentration of Ca^{+2} // Calcium in sarcoplasm can vary the frequency

- Length / tension // how stretched muscle was before it was stimulated

- Temperature // of the muscles – warmed-up muscle contracts more strongly – enzymes work more quickly

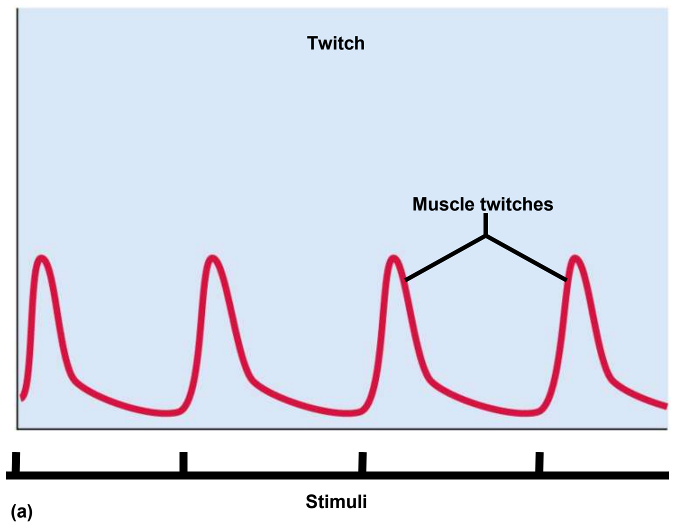
- pH // lower than normal pH of sarcoplasm weakens the contraction // fatigue

- Hydration // state of hydration of muscle affects overlap of thick & thin filaments

Contraction Strength of Twitches

- subthreshold stimulus
  - no contraction at all
- threshold intensity and above
  - a twitch is produced
  - twitches caused by increased voltage are no stronger than those at threshold

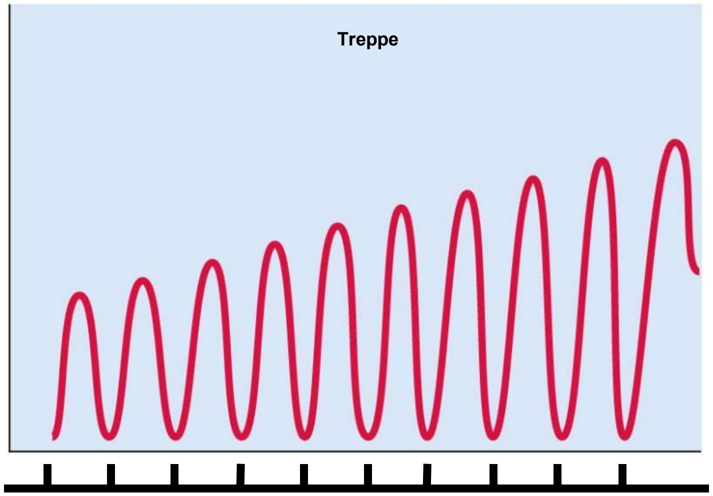
Twitch Strength & Stimulus Frequency



- when stimulus intensity (voltage) remains constant twitch strength can vary with the stimulus frequency

- **up to 10 stimuli per second //** each stimulus produces identical twitches and full recovery between twitches

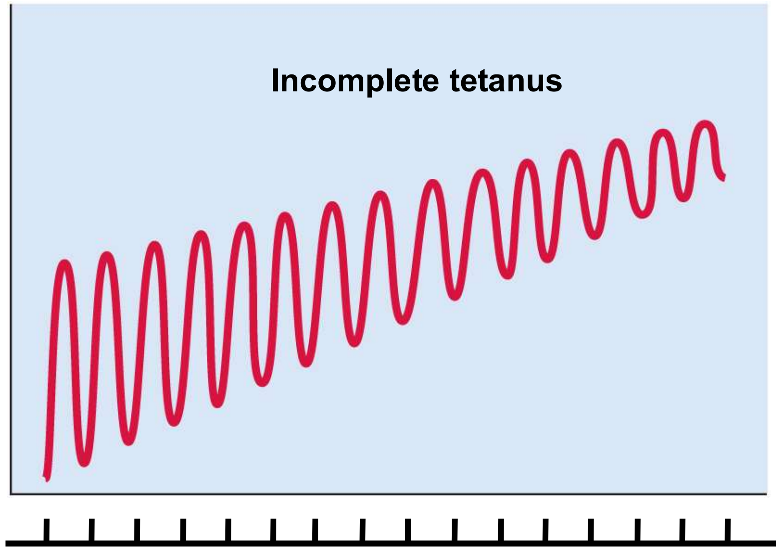
Twitch Strength & Stimulus Frequency



(b)

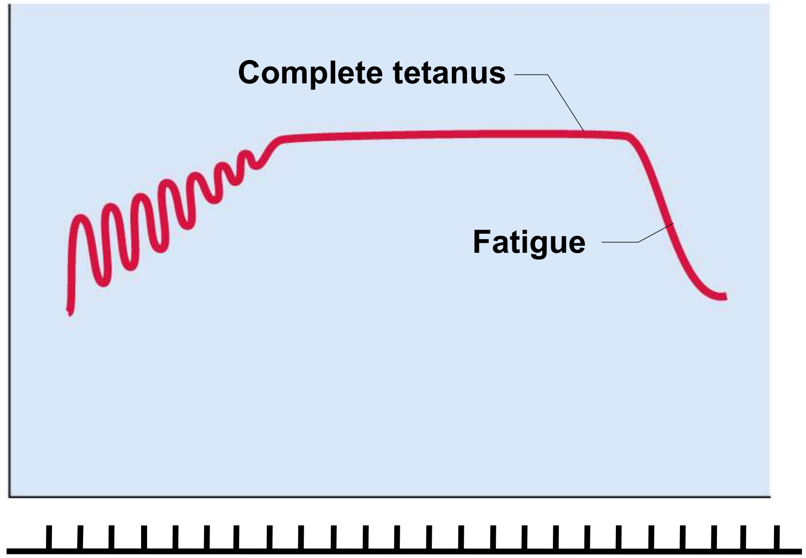
- **10-20 stimuli per second** produces **treppe** (staircase) phenomenon
  - muscle still recovers fully between twitches, but each twitch develops more tension than the one before
  - stimuli arrive so rapidly that the SR does not have time between stimuli to completely reabsorb all of the Ca^{+2} it released
  - Ca^{+2} concentration in the cytosol rises higher and higher with each stimulus causing subsequent twitches to be stronger
  - heat released by each twitch cause muscle enzymes such as myosin ATPase to work more efficiently and produce stronger twitches as muscle warms up

Incomplete Tetanus



- **20-40 stimuli per second** produces **incomplete tetanus**
  - each new stimulus arrives before the previous twitch is over
  - new twitch “rides piggy-back” on the previous one generating higher tension
  - **temporal summation** – results from two stimuli arriving close together
  - **wave summation** – results from one wave of contraction added to another
  - each twitch reaches a higher level of tension than the one before
  - muscle relaxes only partially between stimuli
  - produces a state of sustained fluttering contraction called **incomplete tetanus**

Complete Tetanus



- **40-50 stimuli per second** produces **complete tetanus**
  - muscle has no time to relax at all between stimuli
  - twitches fuse to a smooth, prolonged contraction called complete tetanus
  - a muscle in complete tetanus produces about four times the tension as a single twitch
  - rarely occurs in the body, which rarely exceeds 25 stimuli per second
  - smoothness of muscle contractions is because motor units function asynchronously // when one motor unit relaxes, another contracts and takes over so the muscle does not lose tension

Contraction Strength of Twitches

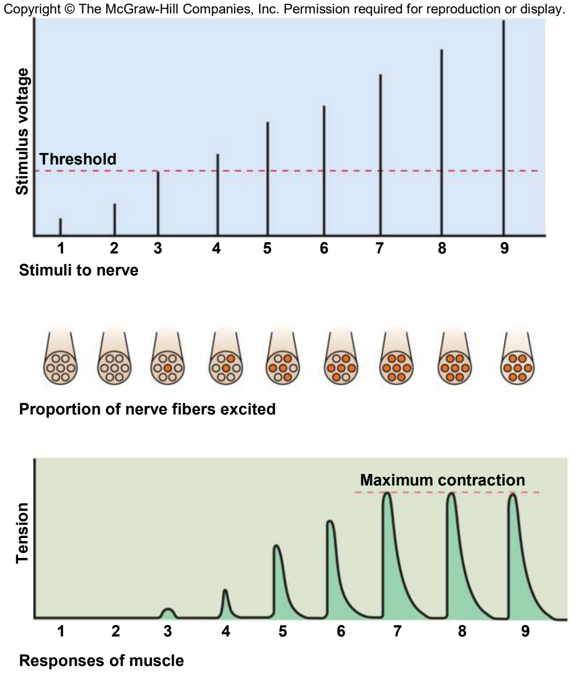
Its not exactly true that muscles obeys an **all-or-none law** (i.e. contracting to its maximum or not at all)

Electrical excitation of a single muscle fiber will follow the all-or-none law

A muscle organ made up of many muscle fibers may not necessarily follow the all or none law

This will depend on the strength of the electrical signal delivered by the nerve!

Recruitment and Stimulus Intensity (1 of 2)

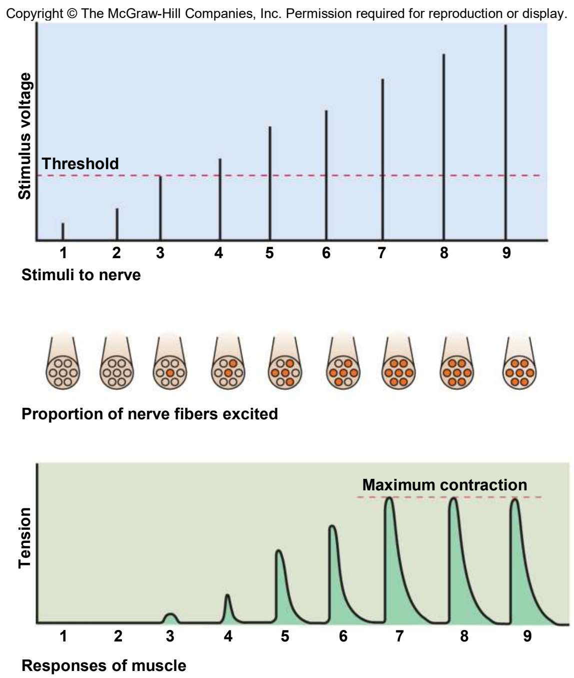


Muscles need to contract with variable strengths for different tasks

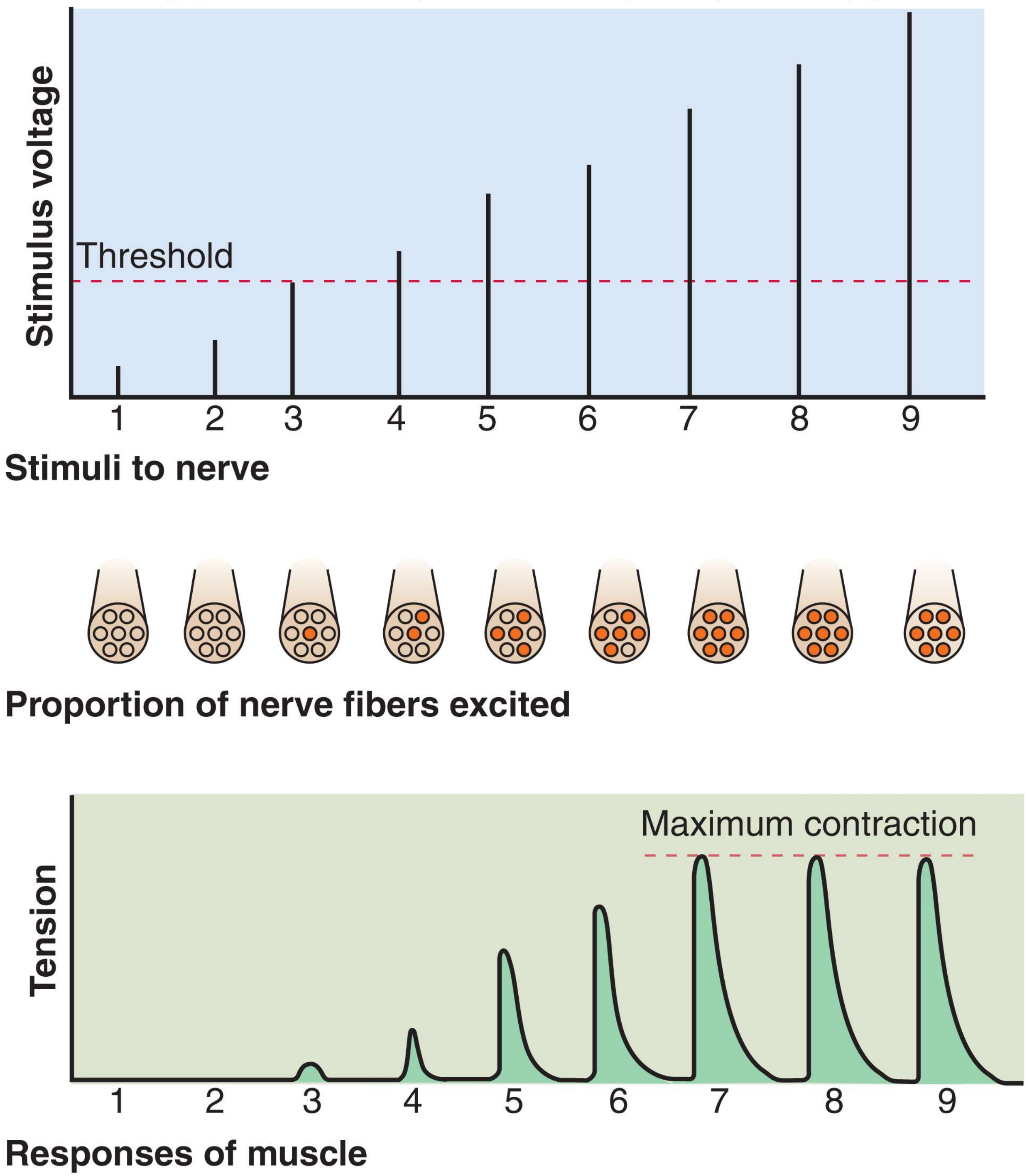
Requires different force of contraction to pick up a bowling ball or a ping pong ball

This is achieved by the relationship between the nerve and the muscle organ

Recruitment and Stimulus Intensity (2 of 2)



- stimulating the nerve with higher and higher voltages produces stronger contractions
  - higher voltages excite more and more nerve fibers in the motor nerve which stimulates more and more motor units to contract
- **recruitment** or **multiple motor unit (MMU) summation** – the process of bringing more motor units into play


Stimulus voltage
Threshold
1
2
3
4
5
6
7
8
9
Stimuli to nerve
Proportion of nerve fibers excited
Tension
Maximum contraction
1
2
3
4
5
6
7
8
9
Responses of muscle