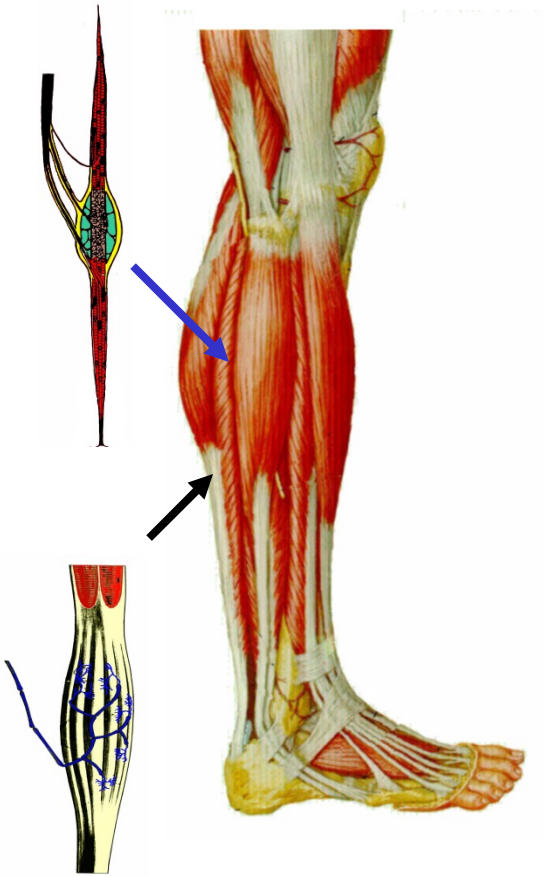
MUSCLE SENSORY CONTROL AND STRETCH REFLEXES - 2021

CONTROL OF POSTURE AND MOVEMENT

MUSCLE SPINDLES



GOLGI TENDON ORGANS

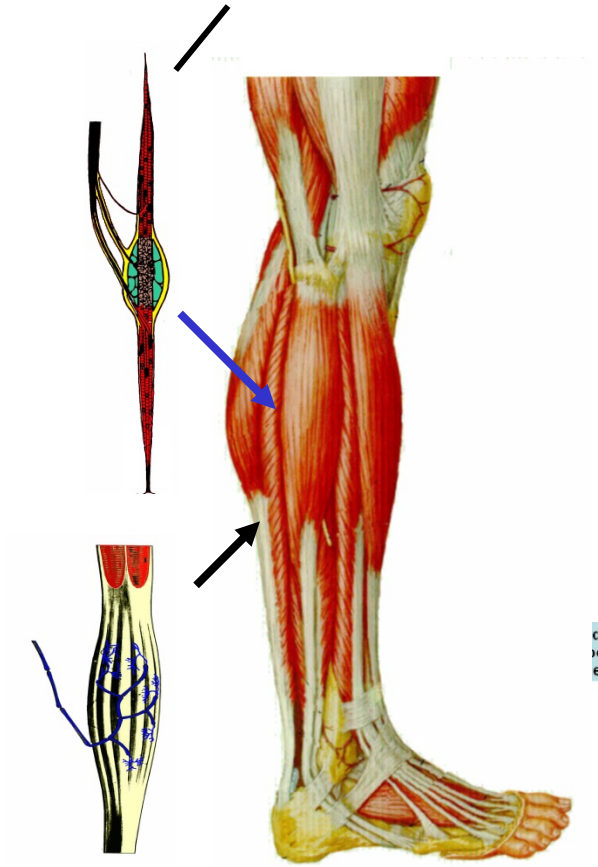
OVERVIEW - MUSCLE RECEPTORS – SENSE ORGANS INSIDE MUSCLES, TENDONS THAT FUNCTION IN CONTROL OF POSTURE AND MOVEMENT.

MAJOR TYPES OF MUSCLE RECEPTORS –
MUSCLE SPINDLES - SIGNAL JOINT POSITION AND MOVEMENT BY MONITORING MUSCLE LENGTH
GOLGI TENDON ORGANS - SIGNAL MUSCLE FORCE.

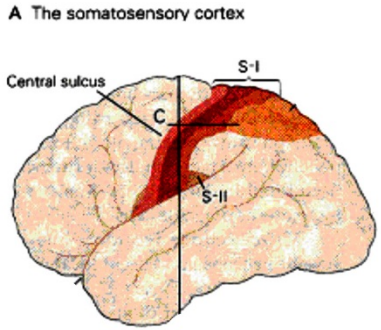
PROBLEM IN UNDERSTANDING FUNCTIONS OF MUSCLE RECEPTORS: MUSCLE RECEPTORS HAVE BOTH CONSCIOUS AND UNCONSCIOUS FUNCTIONS

HOW DOES THE NERVOUS SYSTEM SENSE POSITION, MOVEMENT AND STRENGTH OF MUSCLE CONTRACTIONS? ANSWER: MUSCLE RECEPTORS

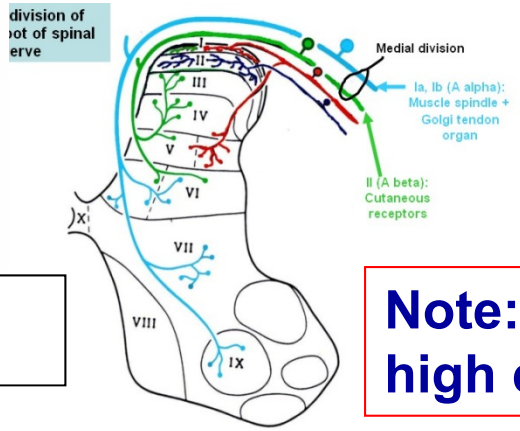
MUSCLE SPINDLES - SIGNAL JOINT POSITION AND MOVEMENT



PROJECTIONS TO BRAIN (CORTEX)



CONNECTIONS IN SPINAL CORD



PROBLEM IN UNDERSTANDING FUNCTIONS OF MUSCLE RECEPTORS: MUSCLE RECEPTORS HAVE BOTH CONSCIOUS AND UNCONSCIOUS FUNCTIONS

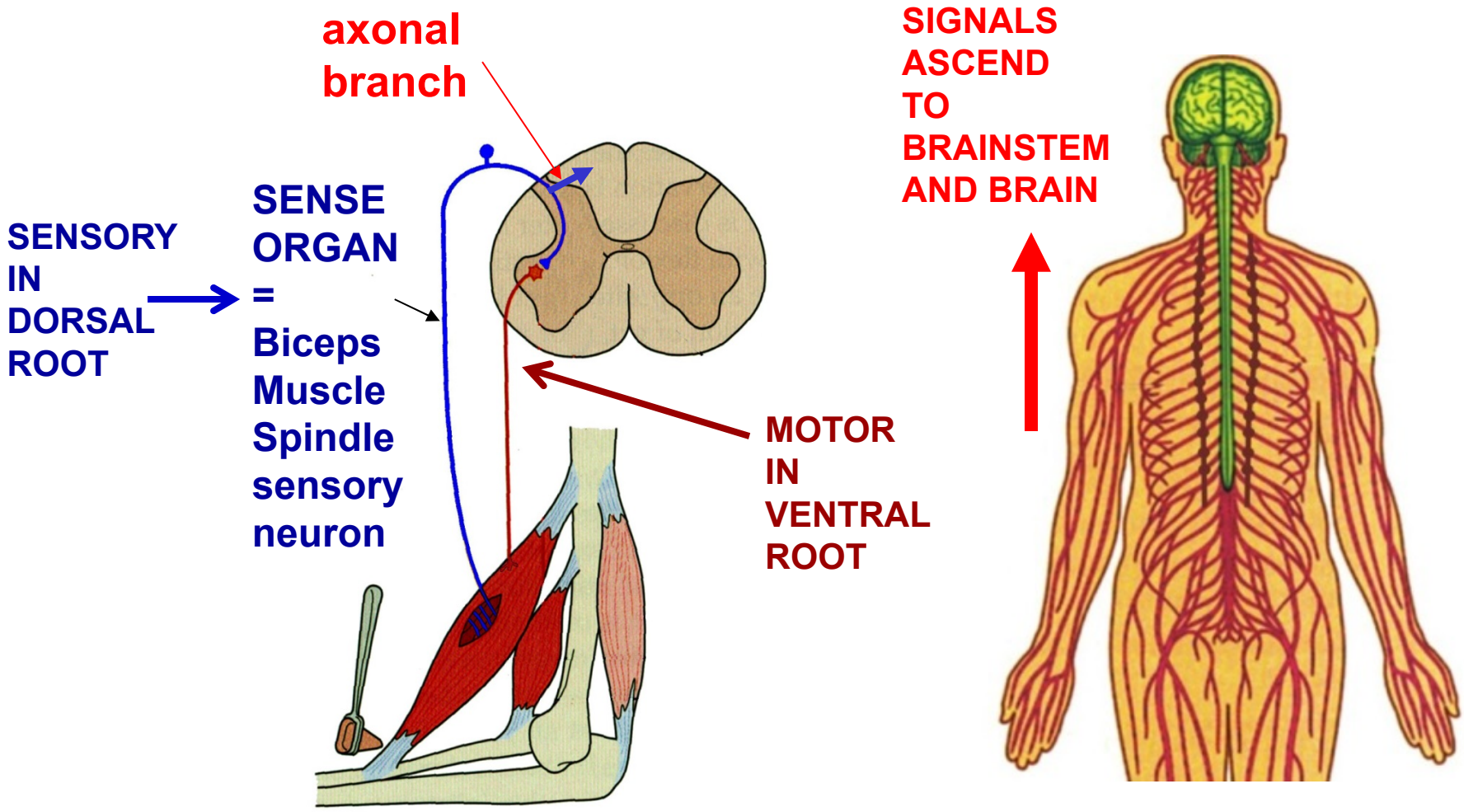
1) CONSCIOUS FUNCTIONS - Signals from muscle receptors reach the cerebral cortex and produce CONSCIOUS sensation (i.e., sense of body position = Kinesthesia).

2) UNCONSCIOUS FUNCTIONS - Muscle receptors make extensive connections in the spinal cord that function without requiring conscious attention. These connections can produce Automatic (reflex) reactions.

GOLGI TENDON ORGANS - SIGNAL FORCE

Note: Muscle receptors have very high conduction velocities (Aα,Aβ)

SENSORY NEURONS BRANCH AND CAN PROJECT TO MANY REGIONS IN CENTRAL NERVOUS SYSTEM



KINESTHESIA: CONSCIOUS SENSE OF BODY POSITION AND MOVEMENT THAT DEPENDS UPON SIGNALS FROM MUSCLE RECEPTORS

Demonstration of Kinesthetic sense: Put your hand's under the table. Without looking at them, Touch the tips of the fingers of one hand to the tips of the fingers of another hand. You know where your hands are without seeing them.

HANDS UNDER TABLE OR TILT YOUR HEAD BACK

TOUCH FINGERS TOGETHER WITHOUT LOOKING AT THEM

FUNCTIONS: 1) KINESTHESIA = CONSCIOUS SENSE OF BODY POSITION; DEPENDS UPON SIGNALS FROM MUSCLE RECEPTORS

Ballet dancers don't have to look at their feet

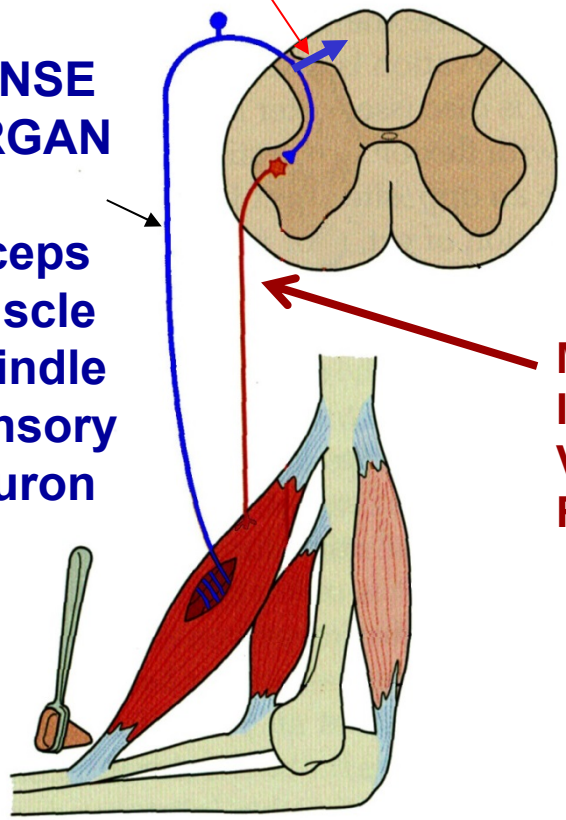
Musical instruments often played without looking at fingers

1) Fine control of body position and movement can be performed without visual inputs (watching them).

2) Use information from sense organs in muscle, tendons and joints called proprioceptors (proprioception = sense of yourself).

Signals from muscle sensory receptors reach thalamus and cortex (via dorsal columns) and contribute to conscious sense of body position.

REFLEX (AUTOMATIC) REACTIONS STRETCH (DEEP TENDON) REFLEXES

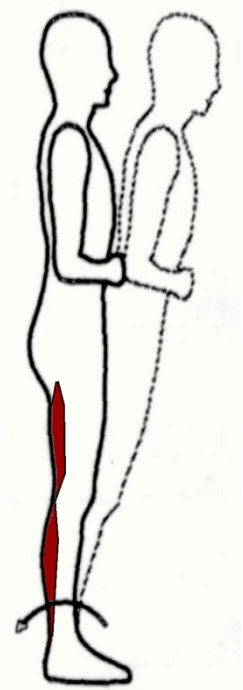


REFLEX TESTING - TENDON TAP EXCITES MUSCLE SPINDLES

AUTOMATIC REACTIONS - STRETCH REFLEX - When a muscle is stretched rapidly, a stretch reflex (automatic reaction) is evoked that causes the stretched muscle to contract. Clinical test: tapping on the tendon of a muscle stretches the muscle and causes it to reflexively contract.

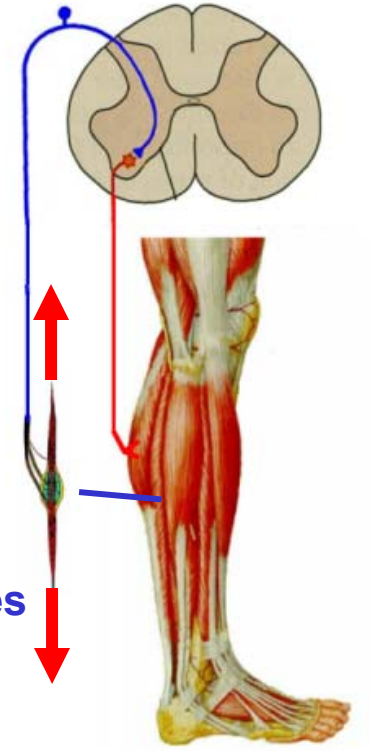
2) UNCONSCIOUS REFLEX AND COMPENSATORY REACTIONS: MAINTAINING BALANCE WHEN STANDING

IF BALLERINA LEANS TOO FAR



MAN STANDING IN MOVING BUS

Tilting forward stretches muscles on back of leg



- Stretch of muscle spindles evokes STRETCH REFLEX in CNS producing contraction of muscle

- Upright posture is maintained by contraction of leg muscles.
- Tilting forward stretches gastrocnemius and also stretches muscle spindles.
- This elicits Stretch reflex in CNS causing muscle to contract.
- THESE REACTIONS ARE PRODUCE AUTOMATICALLY AND DO NOT REQUIRE CONSCIOUS AWARENESS

GUILLAIN-BARRE SYNDROME: IN RARE CASES, PERIPHERAL NEUROPATHY CAN PRODUCE LOSS OF SENSATION WITHOUT MOTOR DEFICITS

Lose prioprioception; also lose kinesthesia (conscious sense of body position)

NERVOUS SYSTEM USES INFORMATION FROM MUSCLE RECEPTORS TO CONTROL WALKING

VIDEO INCLUDED ON WEBSITE: THE MAN WHO LOST HIS BODY (supplementary not on quiz or exam)

Clinical Correlate: Peripheral neuropathies produce loss of axons in peripheral nerves; in rare cases, patients can lose all proprioception (loss of neurons with large axons) and have no sense of body position but no motor deficits; patients train themselves to use vision (exteroception) to compensate for proprioceptive loss (+ circumductive gait).

DEFINITIONS: PROPRIOCEPTION AND KINESTHESIA

1. TYPES OF SENSATION (SOMATOSENSORY)

PROPRIOCEPTION = DETECTION OF POSITION AND MOVEMENT OF BODY ITSELF

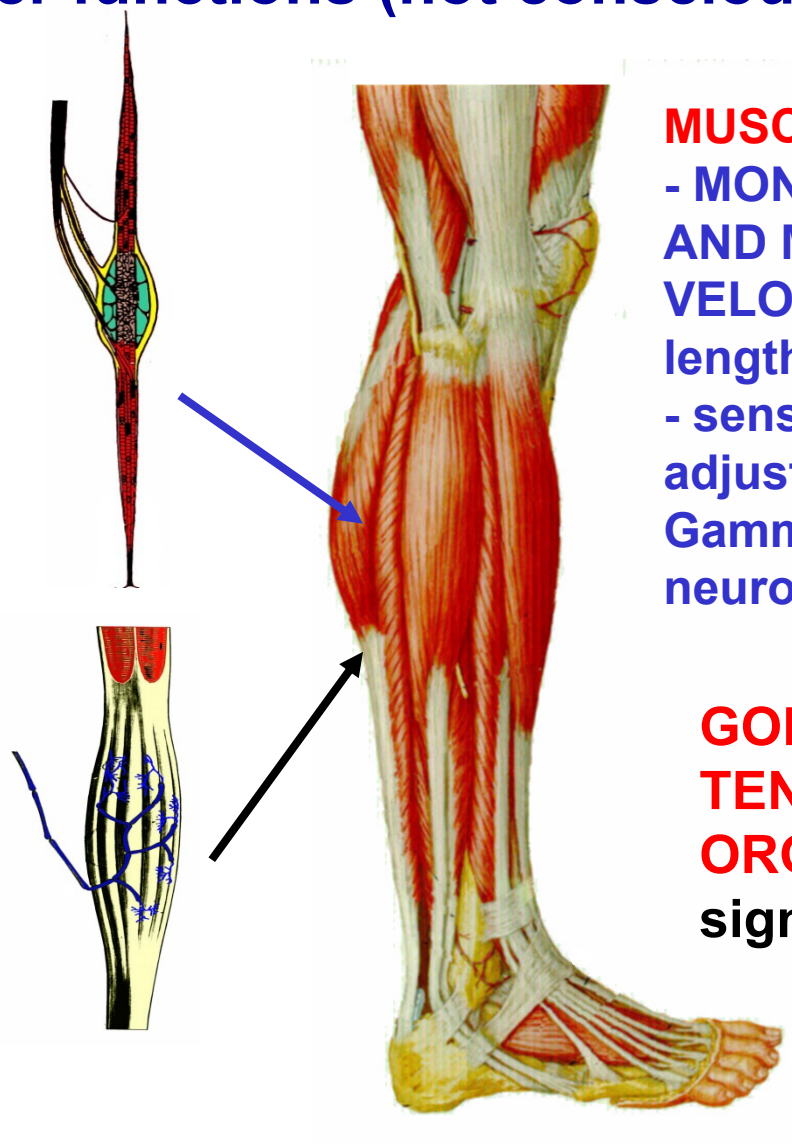
EXTEROCEPTION = DETECTION OF OUTSIDE WORLD (EX. EXTERNAL RECEPTORS TOUCH, TEMPERATURE)

2. KINESTHESIA = CONSCIOUS AWARENESS OF BODY POSITION AND MOVEMENT; DEPENDENT UPON SIGNALS FROM MUSCLE SENSORY RECEPTORS; TRANSMITTED IN PATHWAYS THAT REACH THE BRAIN (THALAMUS AND CORTEX).

C. Overview – Muscle receptors contribute to Kinesthesia but also have other functions (not conscious)

MUSCLE SPINDLES:
1) specialized muscle cells that have both sensory and motor innervation (gamma motor neurons)
2) sensory neurons sensitive to muscle stretch (Note: Spindle is a shape like rod with tapered ends)

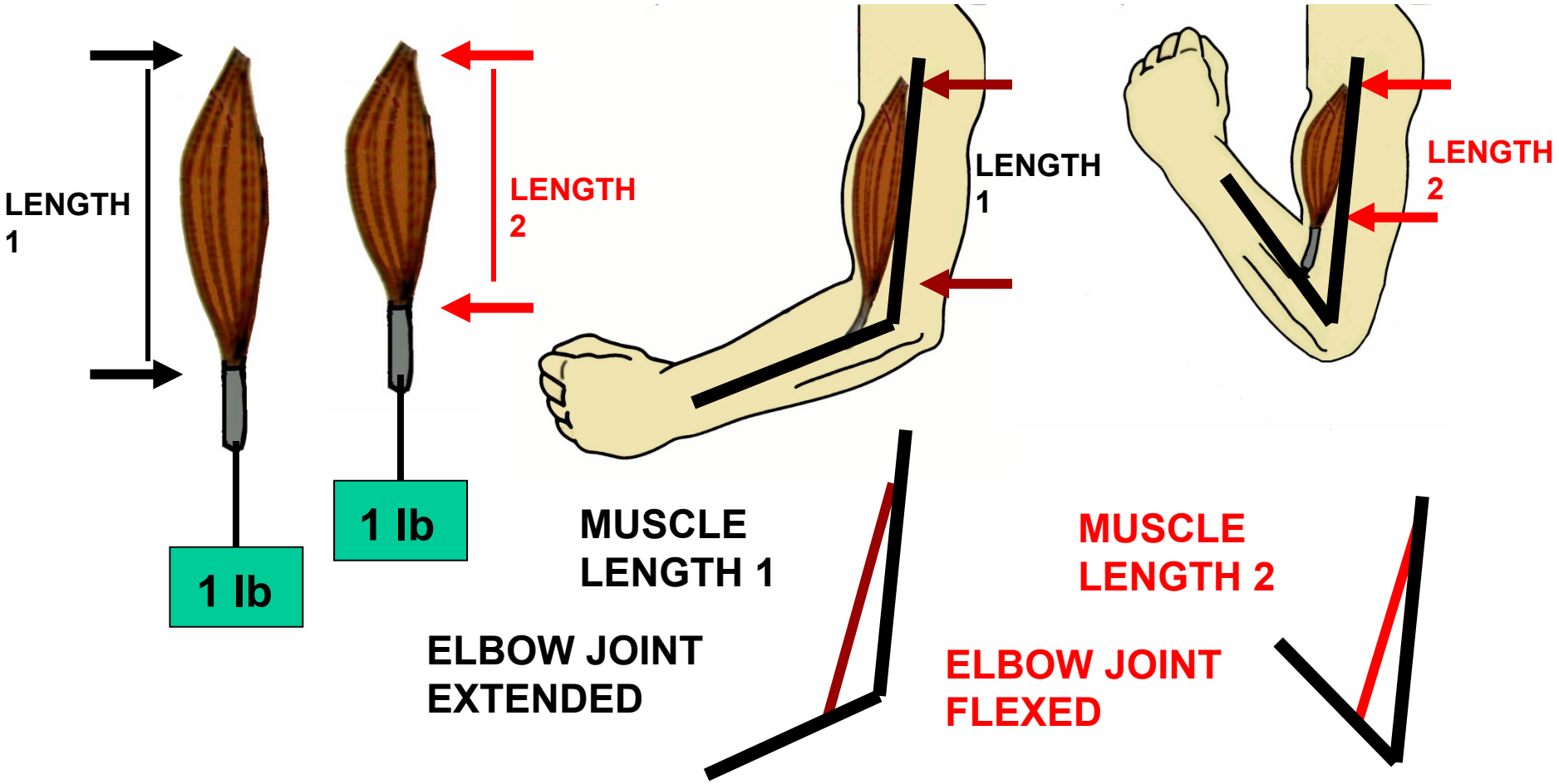
GOLGI TENDON ORGANS:
1) nerve endings located in muscle tendons or connective tissue attachments
2) sensitive to tension in tendon



MUSCLE SPINDLES -
- MONITOR POSITION AND MOVEMENT VELOCITY (change in length/time);
- sensitivities adjusted by Gamma motor neurons

GOLGI TENDON ORGANS -
signal FORCE

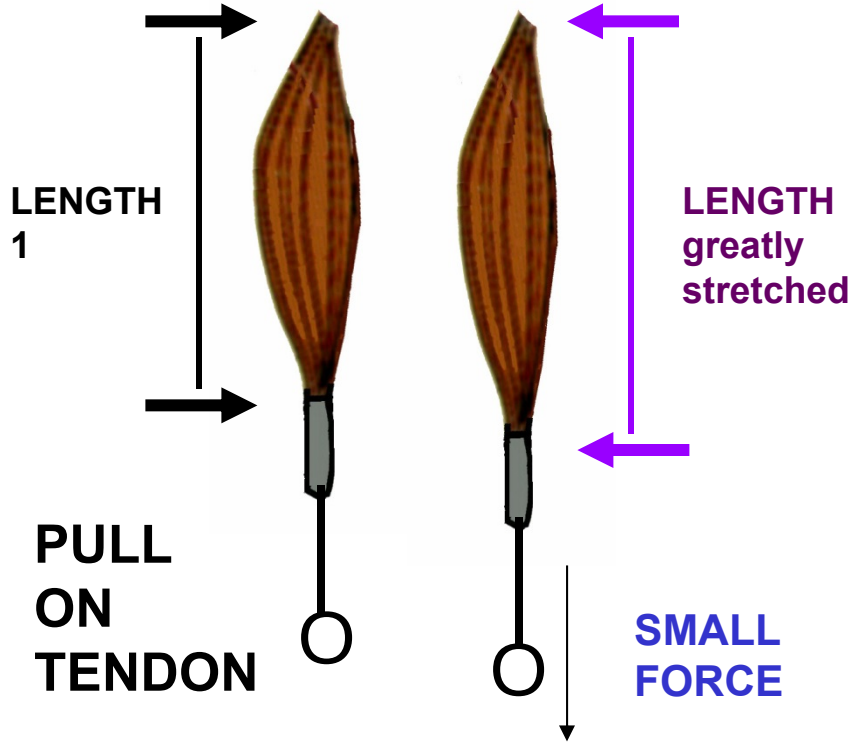
II. MUSCLE PROPERTIES: DETERMINING BODY POSITION FROM MUSCLE LENGTH



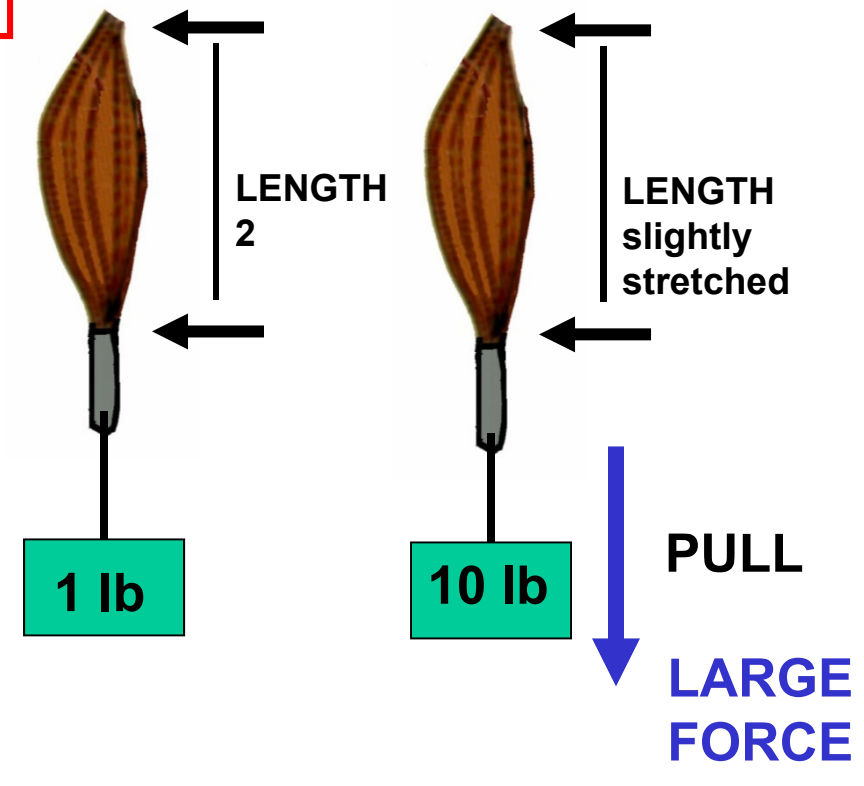
When a muscle contracts it gets shorter (isotonic contraction); If know length of muscles in a limb, can calculate limb position (joint angles). If know how fast lengths of muscles are changing (velocity), can calculate rate of limb movement (nervous system does this).

MUSCLE TONUS definition = **muscle tension at rest**; **due to activities in alpha motor neurons at rest**

TEST TONUS - SLOW STRETCH OF RELAXED MUSCLE



TEST MUSCLE STRENGTH - TELL PATIENT TO RESIST STRETCH



TEST TONUS - When relaxed, muscle cells are easily stretched; also called passive stretch (because physician is producing movement not patient) ; **BECAUSE MOVEMENT IS SLOW, ONLY MODERATE EXCITATION OF MUSCLE SPINDLES.**

TEST STRENGTH – Tell patient to contract muscle against a resistance (ex. physicians holds patients arm); when contracted (or in rigidity), muscle cells are stiff (hard to stretch); NO MOVEMENT, NO INCREASE MUSCLE SPINDLES; GOLGI TENDON ORGANS FIRE TO ENCODE FORCE

CLINICALLY TESTING MUSCLE TONUS = muscle tension at rest; due to activities in alpha motor neurons at rest

Video used by permission of Paul D. Larsen, M.D., University of Nebraska Medical Center; http://library.med.utah.edu/neurologicexam

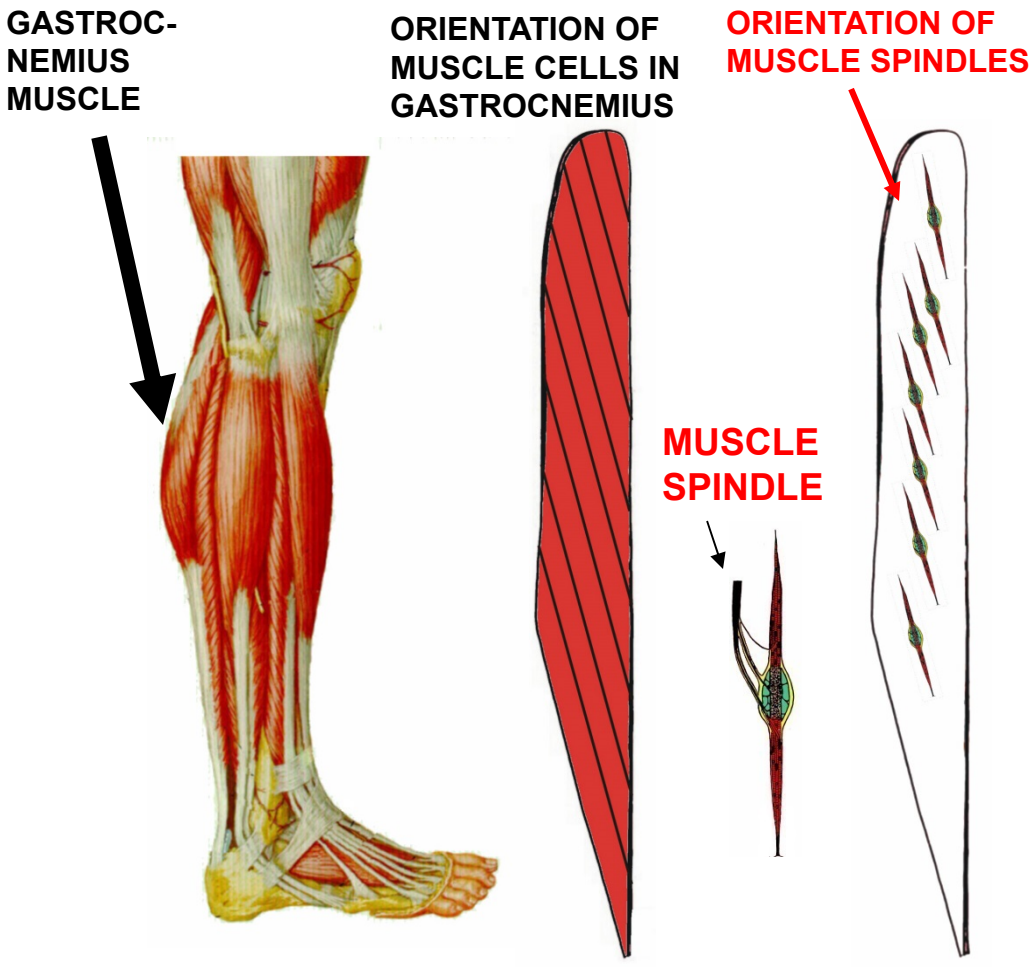
1) FIRST TELL PATIENT TO RELAX,

then

2) APPLY SLOW STRETCH

CLINICAL - Changes in tonus can be an important clinical sign: tonus is increased in Upper Motor Neuron Disorders (discussed in Neuroanatomy)

III. MUSCLE SPINDLE - STRUCTURE



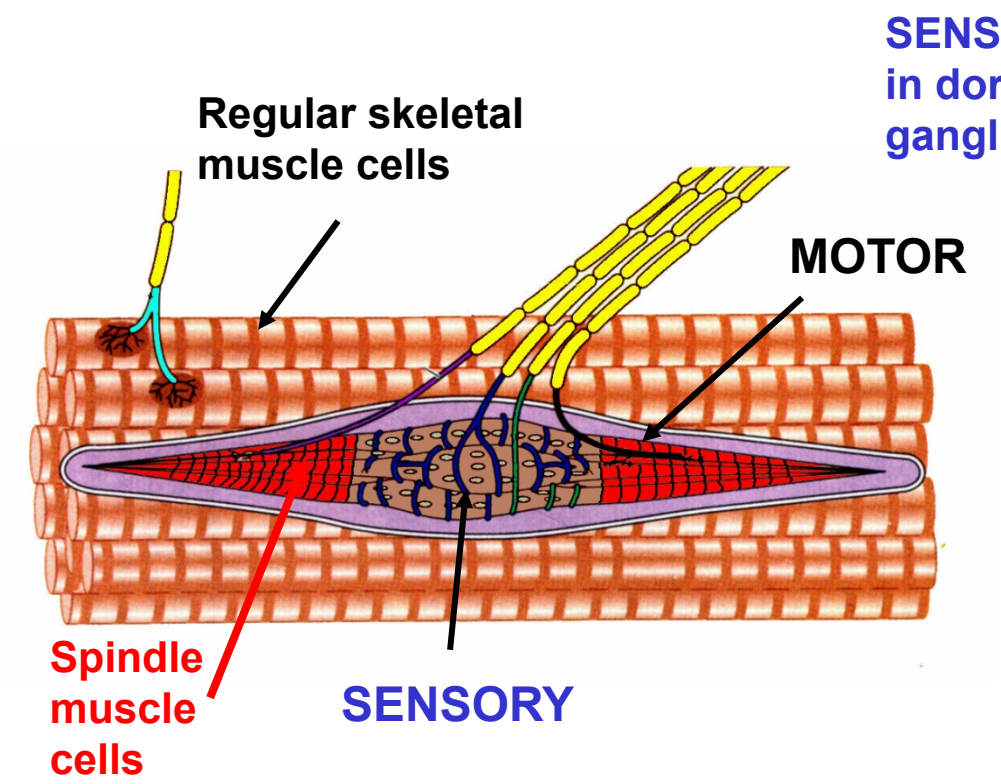
Muscle spindles are found <u>inside muscle</u> among regular muscle cells.

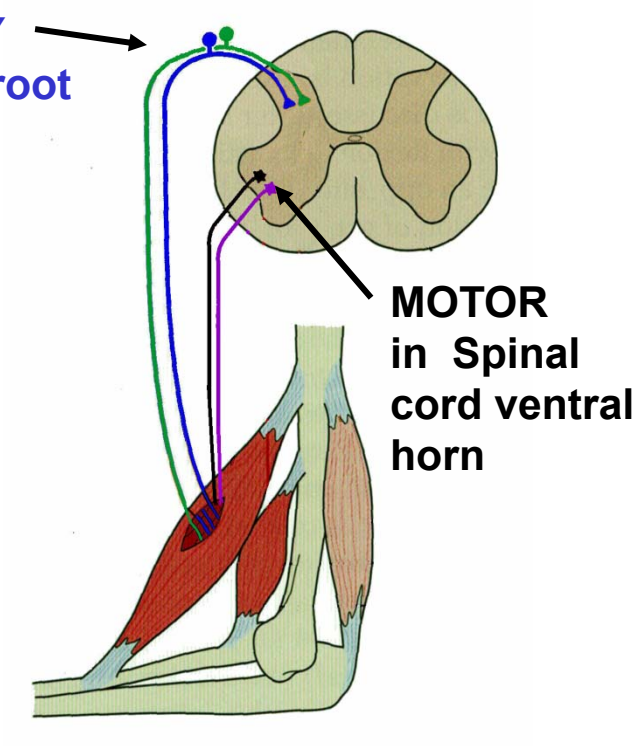
A. oriented <u>PARALLEL</u> to regular muscle cells.

B. Number varies in different muscles - <u>20 to several hundred</u> per muscle. <u>Density</u> (number of muscle spindles/number of regular muscles cells) is <u>highest in muscles used in fine control</u> (ex. small interosseus muscles of hand or extraocular muscles of eye that move eye)

WHEN MUSCLE IS STRETCHED, MUSCLE SPINDLES ARE STRETCHED (BECAUSE OF PARALLEL ORIENTATION)

C. STRUCTURE AND CONTRACTILE PROPERTIES OF SPINDLE MUSCLE CELLS



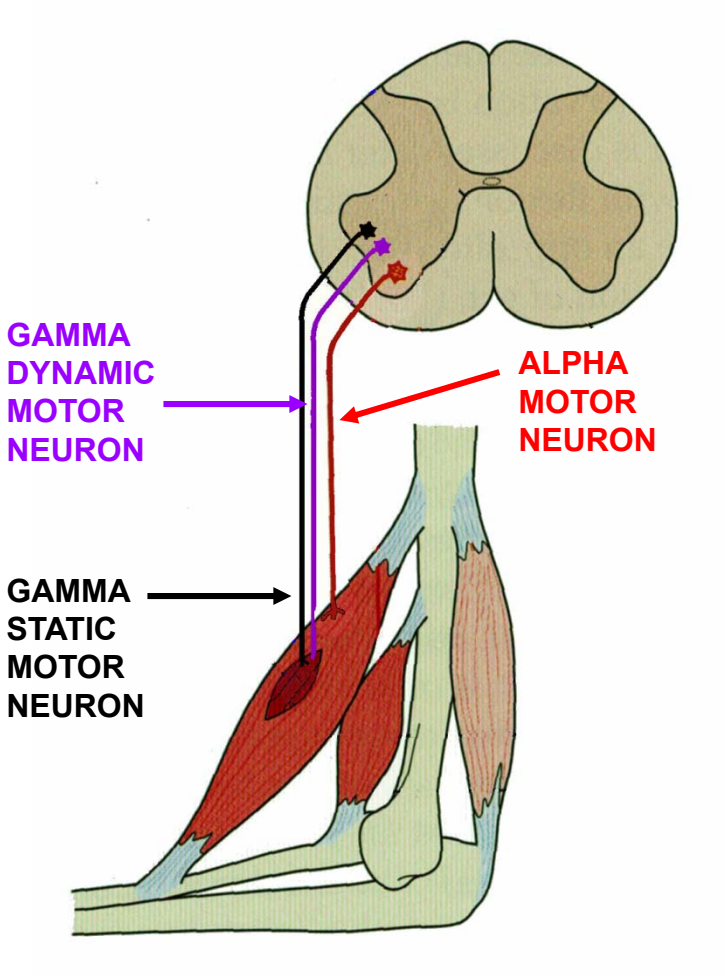


Spindle muscle cells are specialized skeletal muscle cells innervated both by Sensory neurons (cell bodies in dorsal root ganglia) and Motor neurons (cell bodies in ventral horn); there are fast and slow contracting muscle cells in each spindle.

Terminology: Spindle in Latin is fusus; Muscle cells inside spindle = Intrafusal cells

All Regular muscle cells (outside spindle) = Extrafusal cells; Muscle Fiber = Muscle Cell

D. MOTOR INNERVATION OF MUSCLE SPINDLE - spindle muscles cells received their own innervation by gamma motor neurons



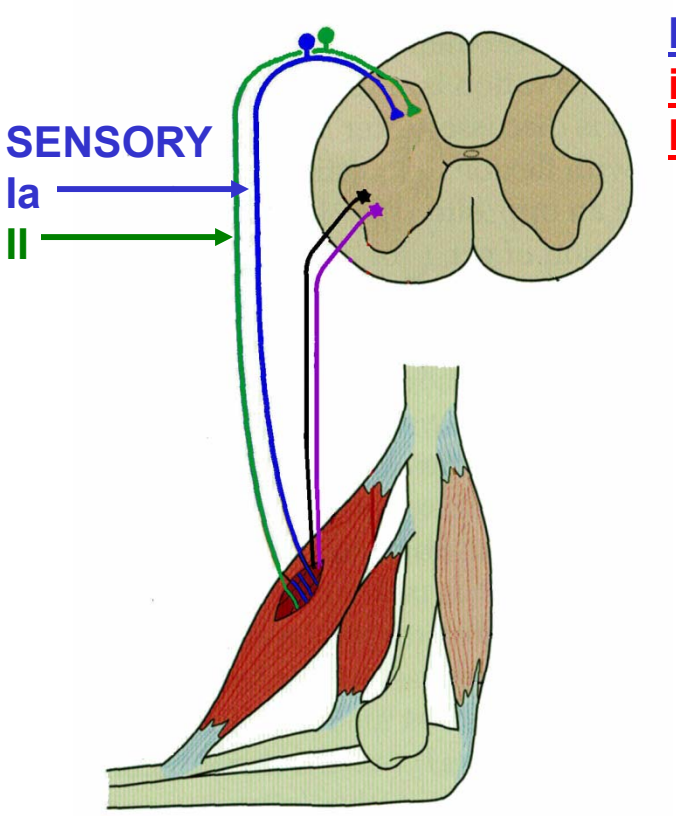
GAMMA MOTOR NEURONS - INNERVATE ONLY SPINDLE MUSCLE CELLS (NOT REGULAR MUSCLE CELLS)

- smaller (1-8 microns axon diameter) than alpha motor neurons;
- form up to 30% of all axons in ventral roots
- Firing of gamma motor neurons causes the spindle muscle cells to contract but this does NOT generate much force at the muscle tendon.
- There are fast and slow Gamma motor neurons (matching spindle muscle cells)

NOTE: NO SELECTIVE, VOLUNTARY CONTROL OF GAMMA MOTOR NEURONS

E. SENSORY INNERVATION OF MUSCLE SPINDLE

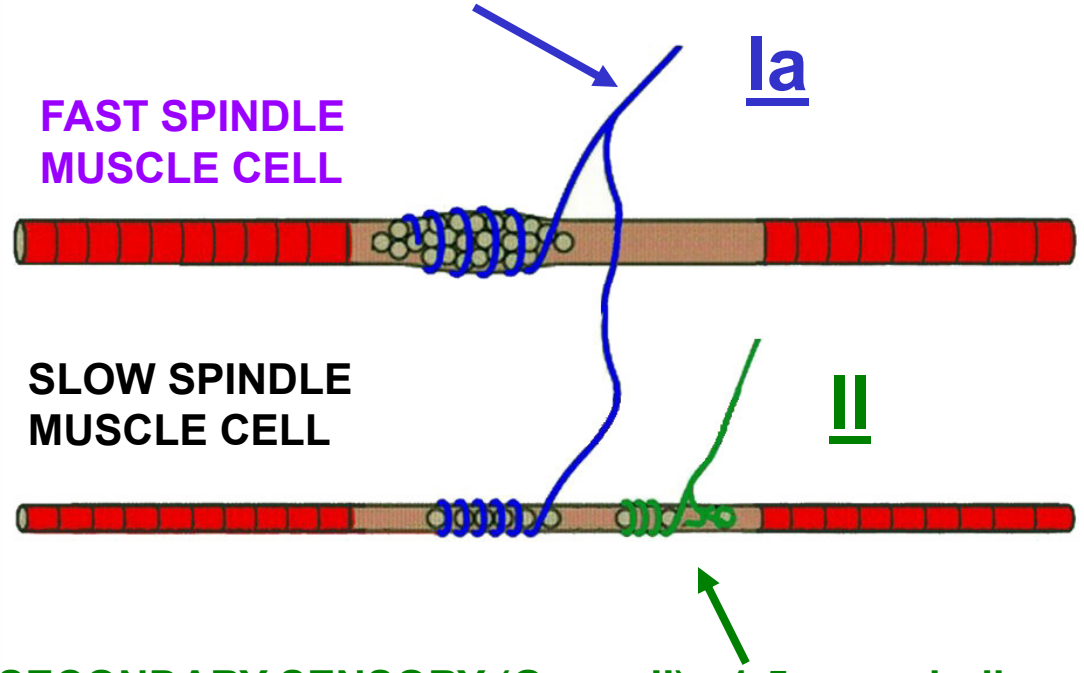
All sensory neurons in the muscle spindles detect stretch of muscle.



Ia = Primary

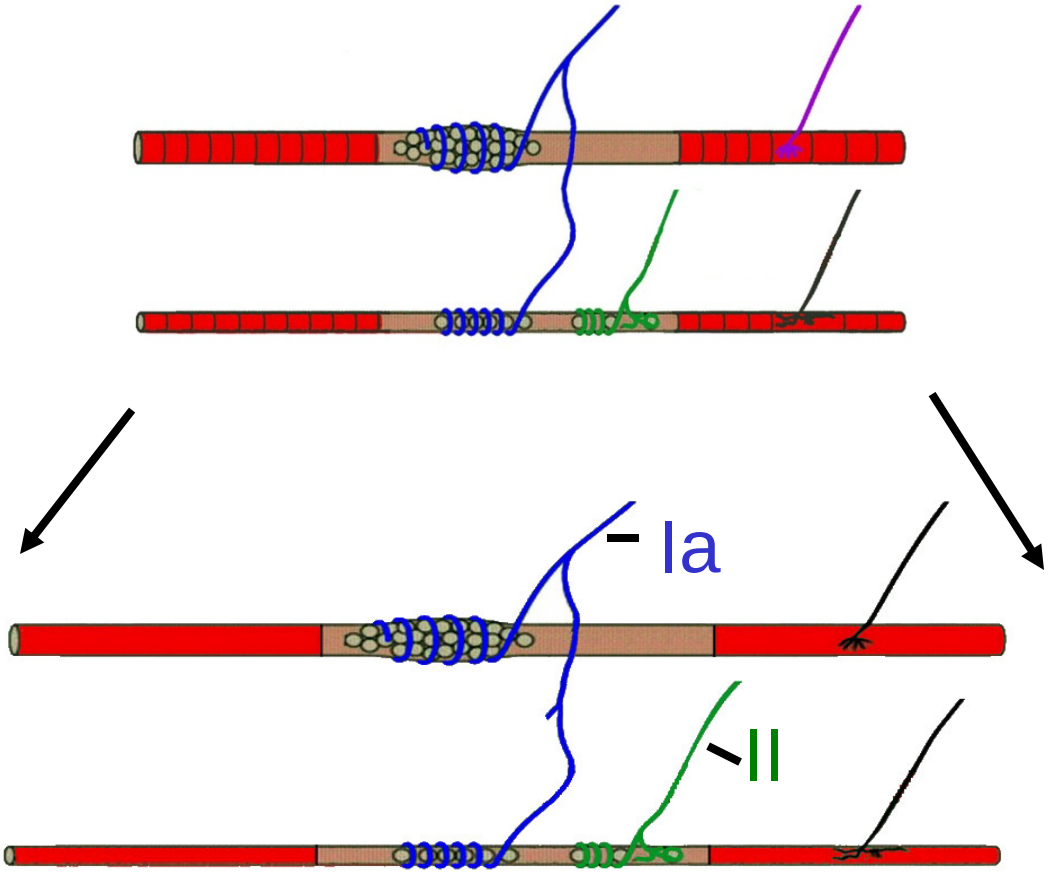
II = Secondary

PRIMARY SENSORY (Group Ia) - 1 per spindle; innervates All muscle cells; DETECT LENGTH AND RATE OF CHANGE OF LENGTH

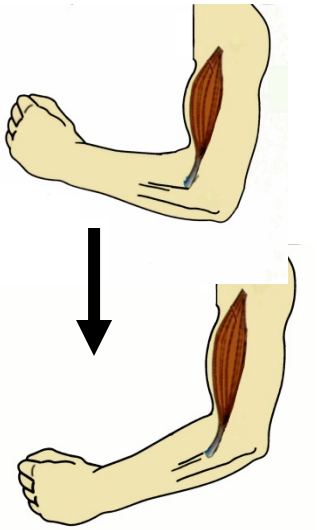


SECONDARY SENSORY (Group II) - 1-5 per spindle; innervates ONLY Slow contracting muscle cells (not Fast). DETECT ONLY MUSCLE LENGTH (NOT RATE OF CHANGE)

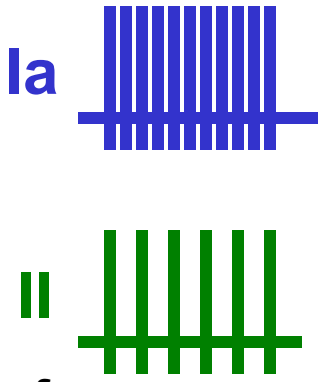
3. MUSCLE SPINDLE SENSORY NEURONS ARE EXTREMELY SENSITIVE TO STRETCH OF MUSCLE



Stretch biceps muscle by extending elbow

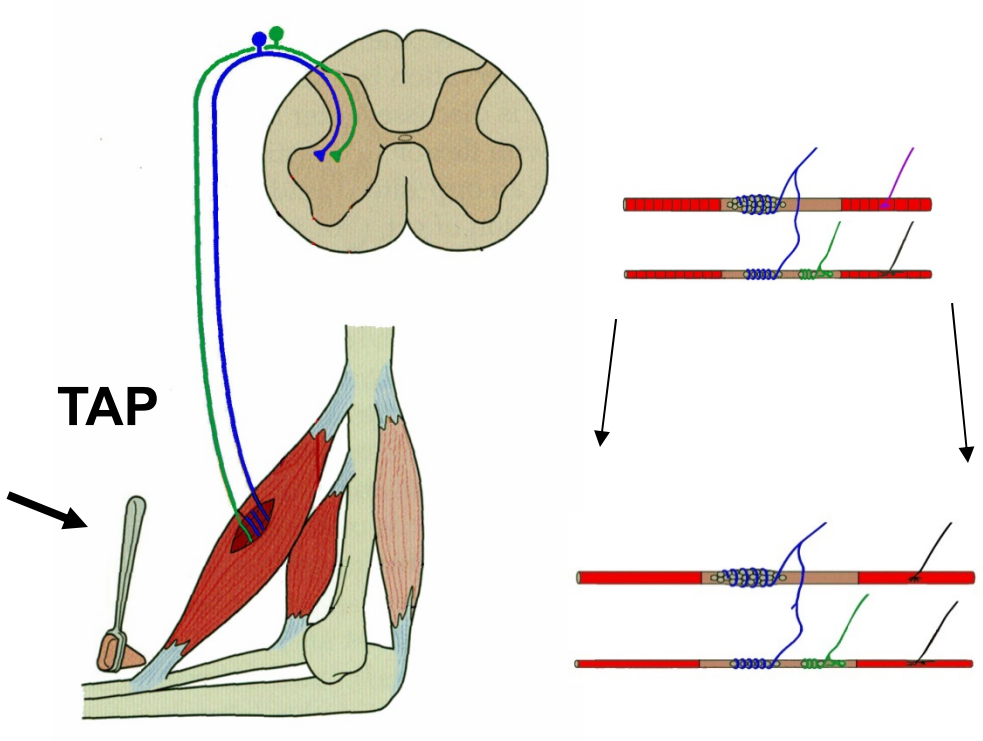


Both Ia and II endings fire

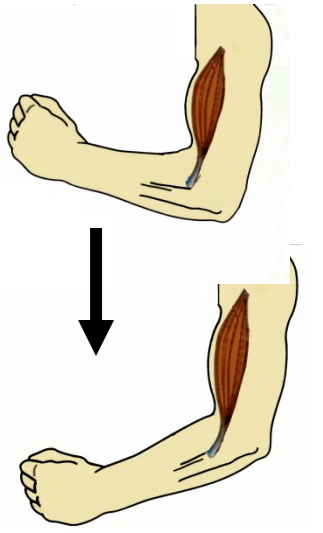


Why? Sensory neurons are mechanoreceptors; membrane of sensory endings (Ia and II) have STRETCH SENSITIVE ION CHANNELS; ion channels open when membrane is stretched

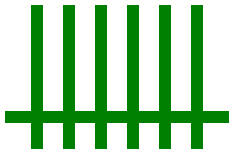
STRETCH REFLEX TESTING – tapping a tendon produces a brief, very fast stretch (lengthening) of the muscle; this activates all spindle sensory neurons



TENDON TAP MIMICS RAPID JOINT EXTENSION



Ia increase firing

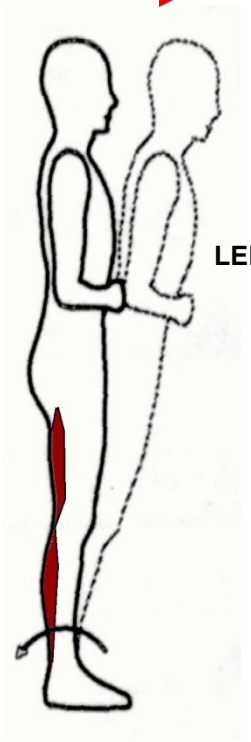


II increase firing

TENDON TAP CAN ACTIVATE ALL MUSCLE SPINDLES SIMULTANEOUSLY: DOES NOT ACTIVATE GOLGI TENDON ORGANS

WHY HAVE SENSITIVITY TO VELOCITY? SENSITIVITY TO RATE OF CHANGE IN LENGTH MAKES REACTIONS TO PERTURBATIONS FASTER

Small, rapid tilt forward *



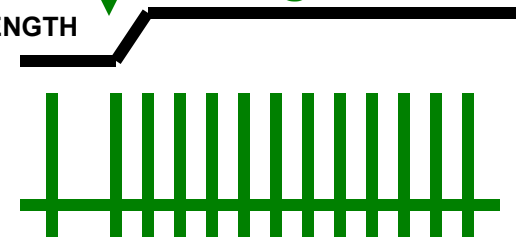
Stretch muscle spindles in Gastrocnemius

Group II

Signal ONLY Length

Slight increase in firing

LENGTH



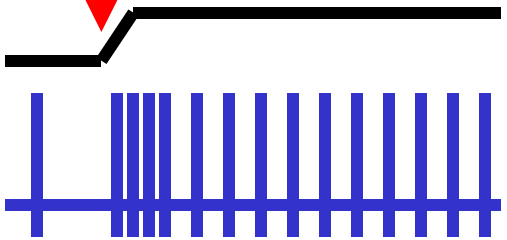
Small, rapid change in length

Small increase in II discharge

Group Ia

Sensitive to Length AND Velocity

INTENSE BURST AT START

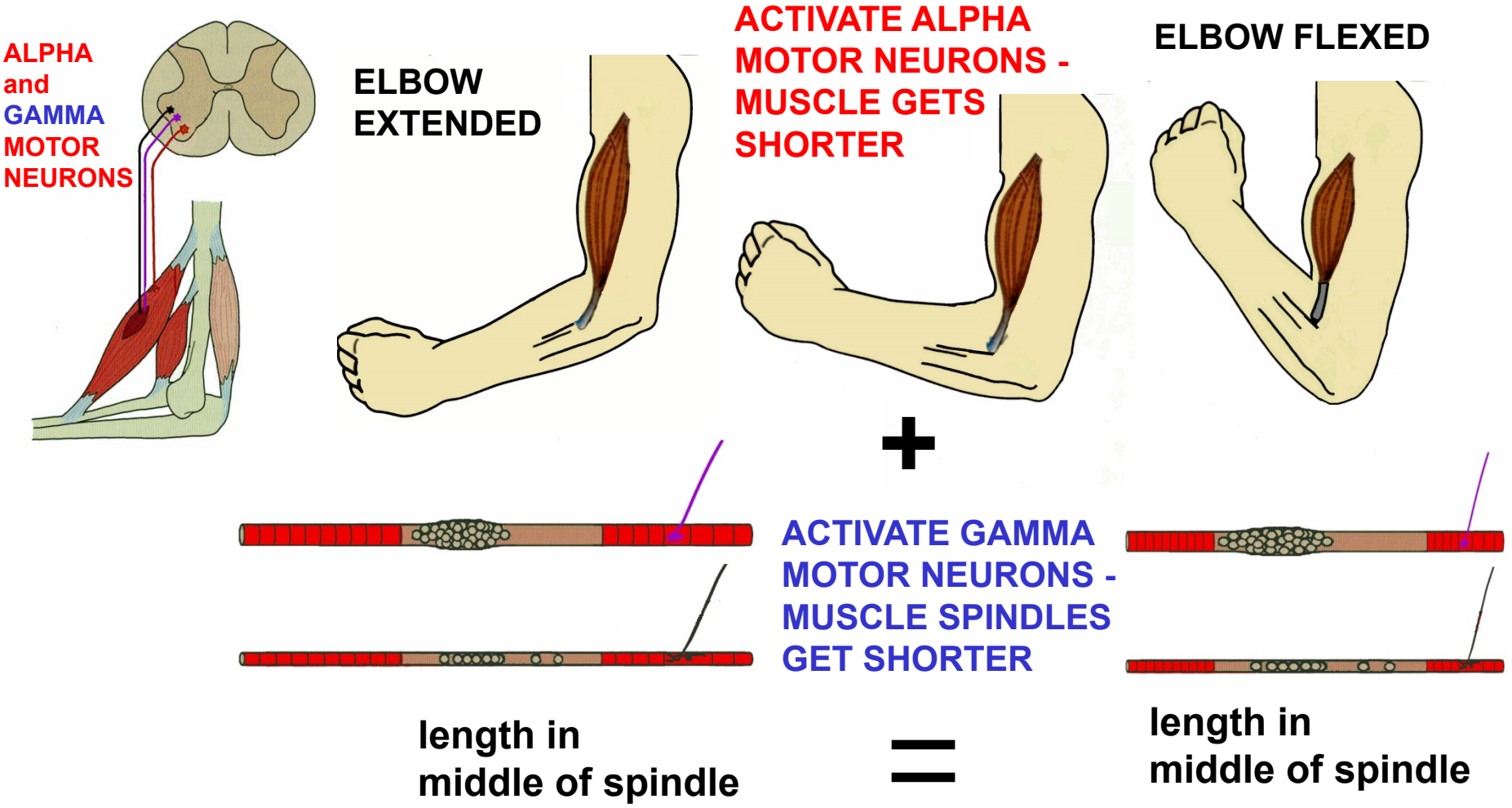


Small, rapid change in length

Large increase in Ia discharge

- Sensitivity to rate of change produces large burst at start of perturbation
- DETECT SWAY BEFORE LARGE MOVEMENT OF BODY OCCURS
- Sensitivity can be enhanced by gamma motor neurons (see following slides)

F. ALPHA-GAMMA COACTIVATION: ADJUSTS AND RESETS MUSCLE SPINDLE LENGTH TO ANY MUSCLE LENGTH



Gamma motor neurons can RESET muscle spindles so they will readily signal stretch from any starting length i.e. from any joint position; perturbations that produce stretch can be detected from any position or during movements.

7. GAMMA DYNAMIC MOTOR NEURONS CAN ENHANCE SENSITIVITIES OF SPINDLE SENSORY NEURONS

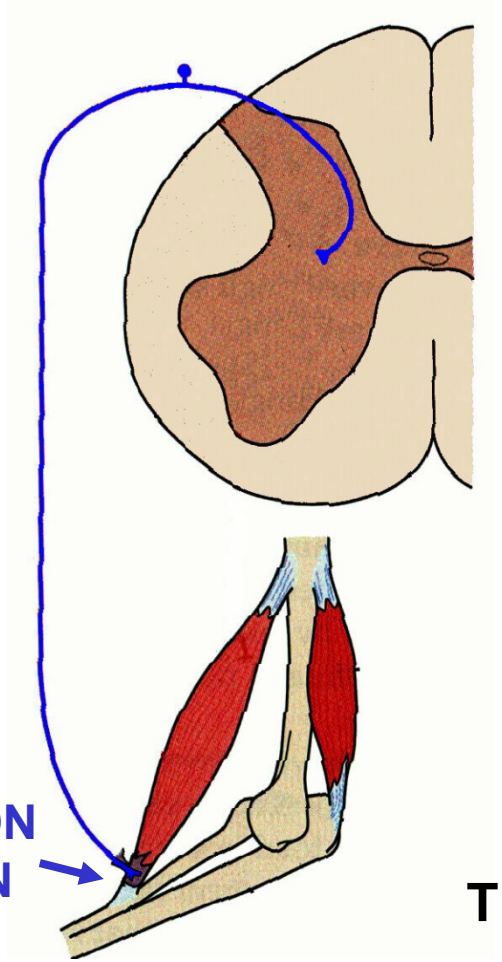
Gamma motor neuron activity is increased in anticipation of perturbations (ex. walking on a thin rope)

Gamma motor neuron activity is increased (probably) in patients who are nervous.

G. WHY PATIENTS MUST BE TOLD TO RELAX BEFORE A NEUROLOGICAL EXAM

- Gamma motor can set sensitivity of muscle spindles; Gamma motor neurons receive inputs via descending motor pathways
-These inputs may contribute to apparently increased reflexes if patients are nervous in a neurological exam.
- Physician should try to get patients to relax before neurological tests.

IV. GOLGI TENDON ORGAN: ENCODES MUSCLE FORCE



GOLGI TENDON ORGAN

REST

SENSORY ENDING

TENDON

MUSCLE CONTRACTS AGAINST RESISTANCE OR PULL ON TENDON WHEN MUSCLE IS CONTRACTED

MUSCLE CONTRACT

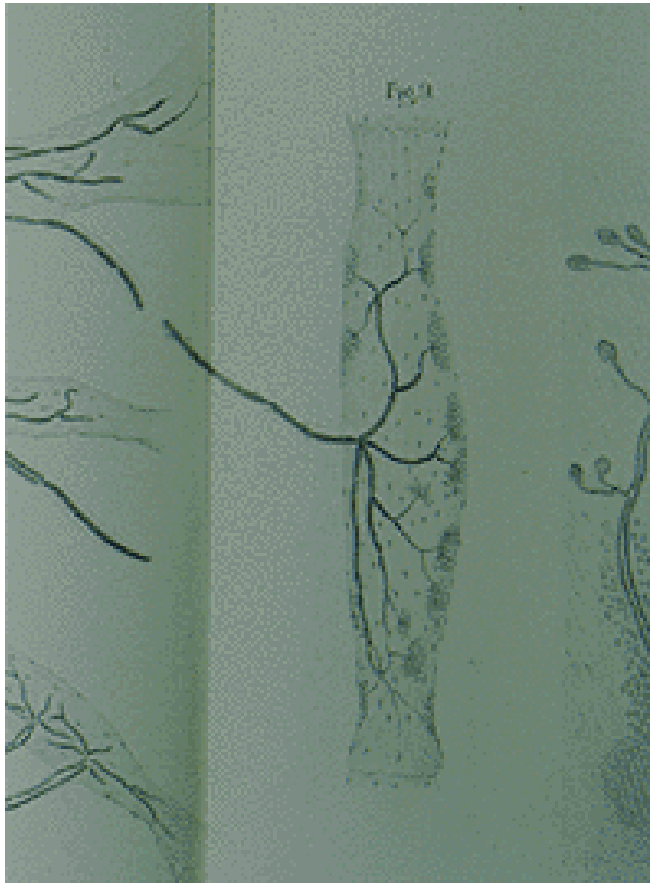
TENDON BECOMES TAUT

Golgi tendon organs - Large (Type Ib) sensory neurons end in muscle tendon or connective tissue attachment (myotendinous junction). Branches intertwine with collagen fibers. Large forces applied to tendon cause it to become taut.

Camillo Golgi 1843-1926

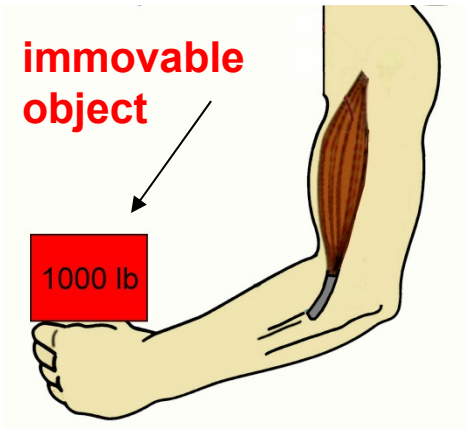
excellent mustache

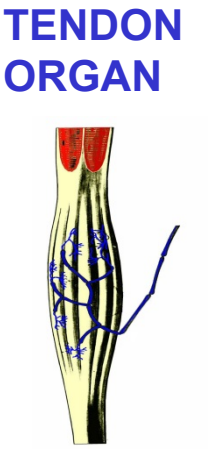
Golgi Tendon Organ

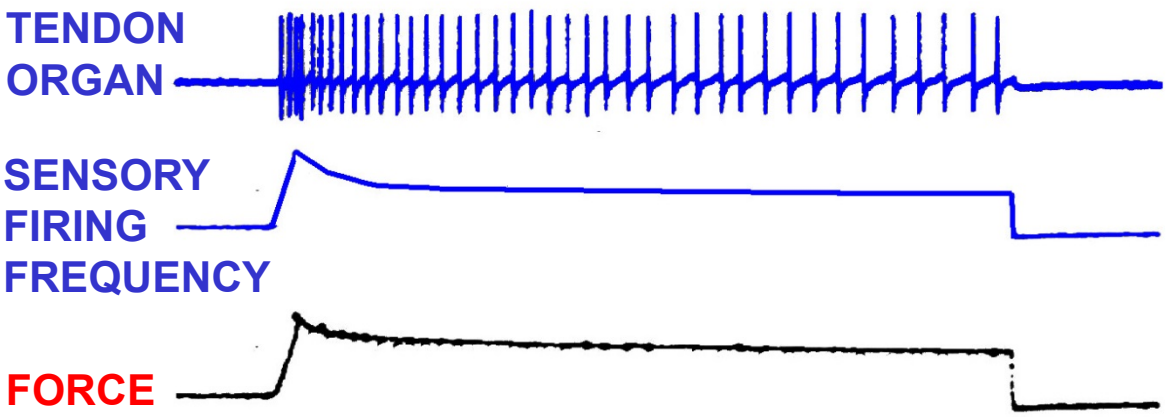


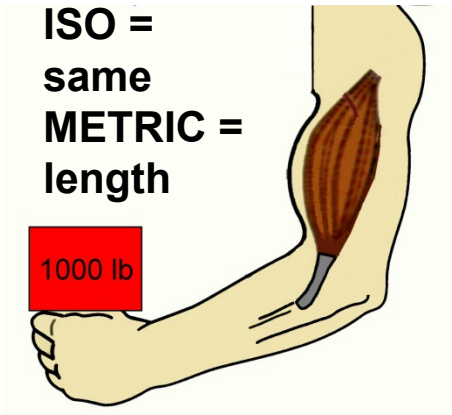
Golgi's original drawing of a tendon organ

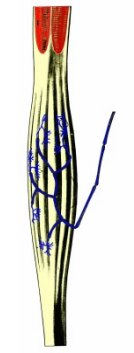
GOLGI TENDON ORGANS DISCHARGE INTENSELY IN ISOMETRIC CONTRACTION (when testing muscle strength)



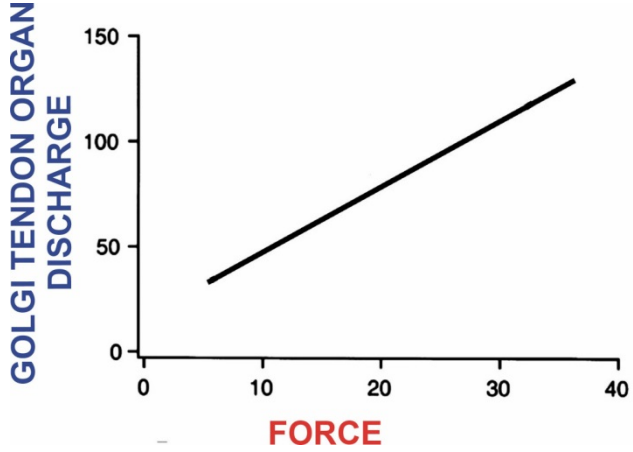






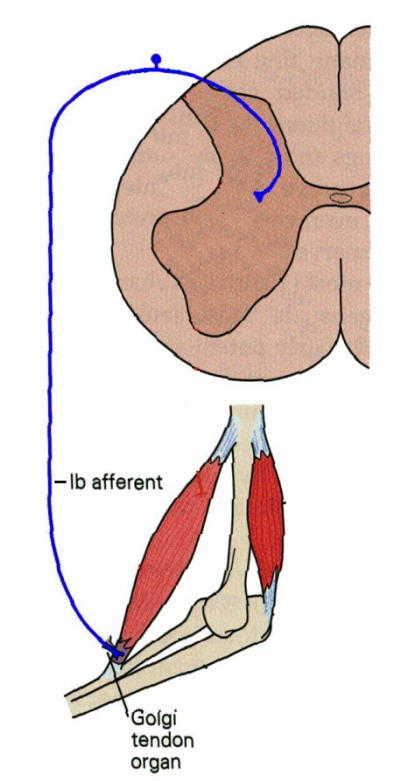


SENSORY DISCHARGE AT DIFFERENT LEVELS OF MUSCLE CONTRACTION

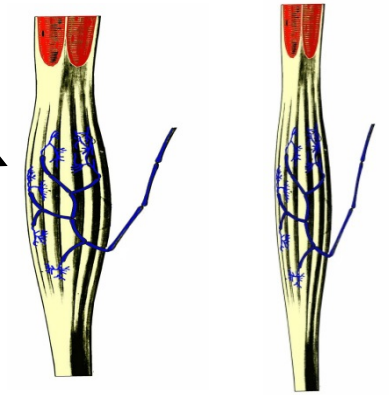


Muscle length stays about same, muscle tendon stretches slightly.
Tendon organ encodes force developed by muscle contraction.
Passive stretch or Tendon tap does NOT excite tendon organs.

REGULATING MUSCLE TENSION



Signals from Golgi tendon organs signal strength of muscle contraction



CLINICAL - GOLGI TENDON ORGANS FIRE INTENSELY TO RESISTED (ISOMETRIC) MUSCLE CONTRACTIONS,

SUMMARY OF PROPERTIES OF MUSCLE SENSORY RECEPTORS

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Sense Organ	Number of sensory neurons per sense organ	Innervates	Signal	Activated by tendon tap in Clinical Test of Stretch reflex
Muscle Spindle Primary Ia	1	All spindle muscle cells (fast and slow contracting)	Movement Velocity and Length	Yes – Fire intensely
Muscle Spindle Secondary II	1-5	Only slow contracting spindle muscle cells	Length NOT velocity	Yes – Fire intensely
Golgi Tendon Organ Ib	1-2	Muscle tendon at junction with muscle cells	Muscle Force	No – do not fire in clinical test