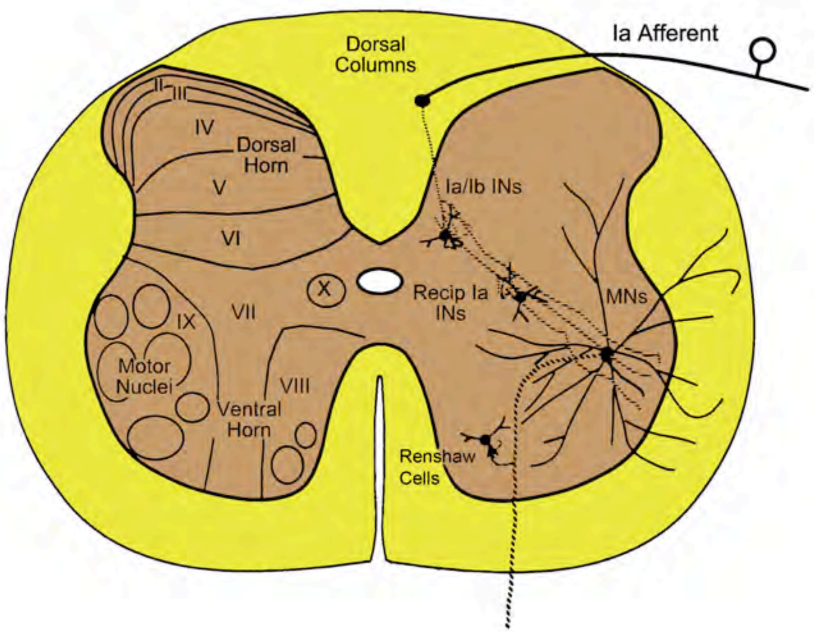
Spinal Cord Reflexes

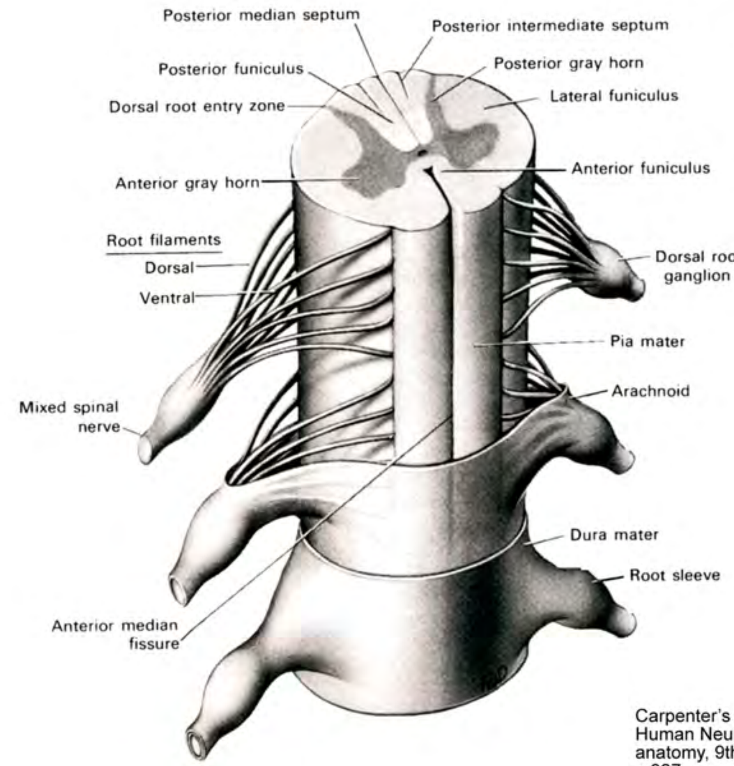
Eric Lang

Graduate Systems Neuroscience Course

NYU

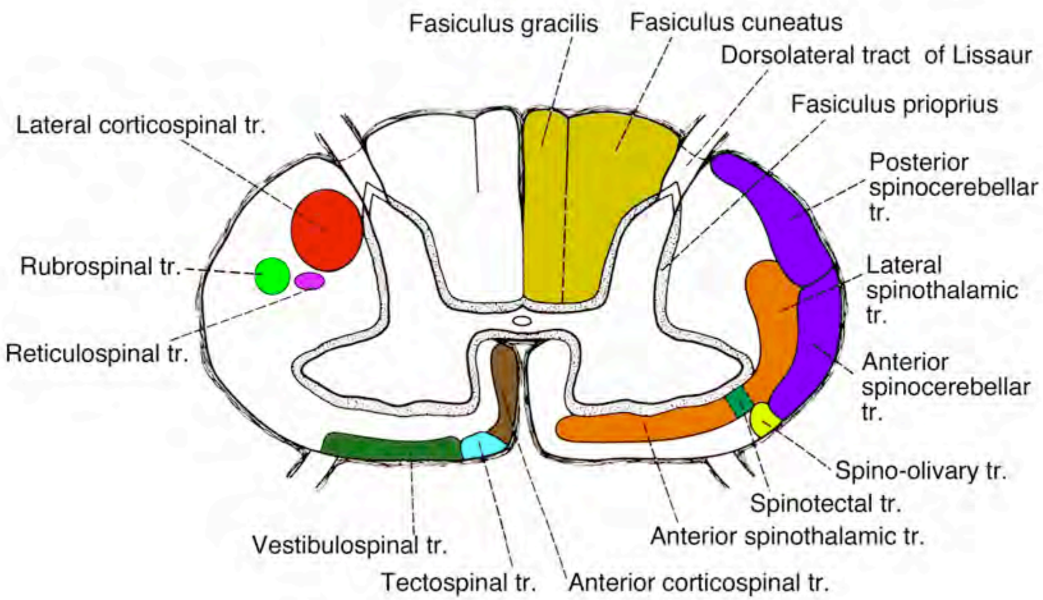


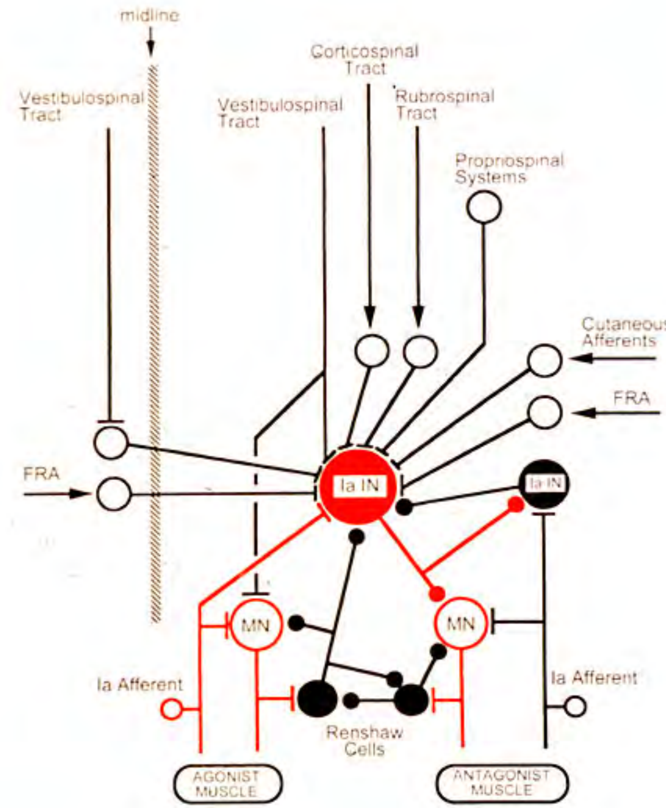
Burke, Syn Org Brain



Carpenter's
Human Neuro-
anatomy, 9th ed
p 327

Spinal cord tracts





Reflexes- basic concepts

Definition

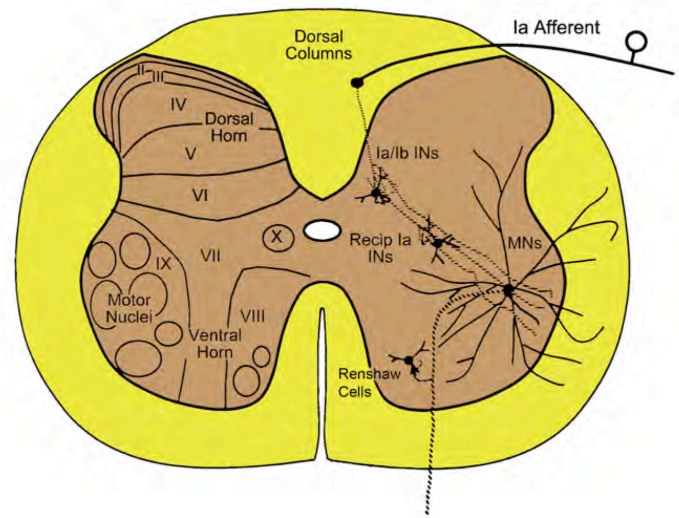
A reflex is a relatively predictable, involuntary, and stereotyped response to a particular stimulus.

Reflex Arc Components

Afferent limb (Ia, Ib, II, FRAs)

Central component (ITNs)

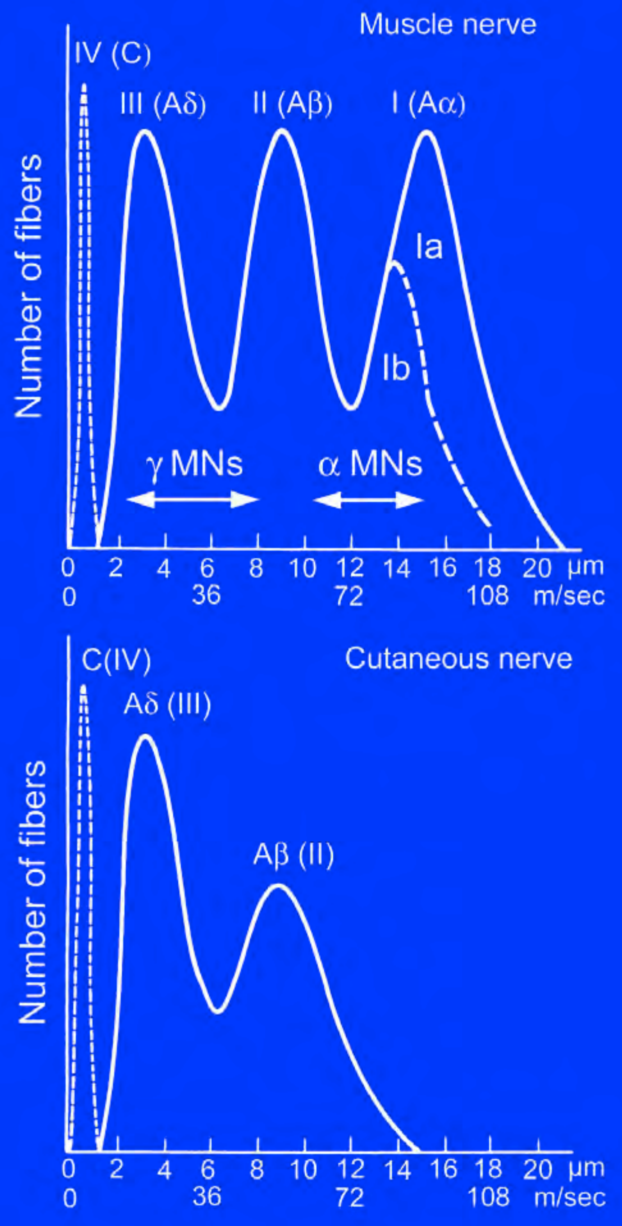
Efferent limb (Motor neurons: alpha) (beta, gamma)



Burke, Syn Org Brain

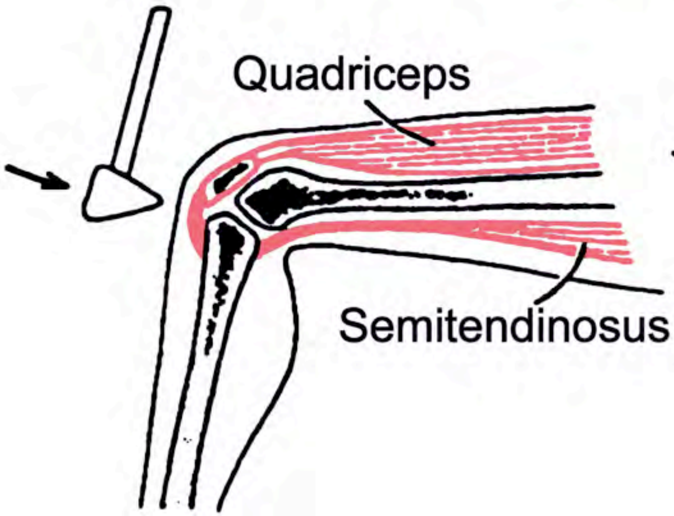
Reflexes and Circuits

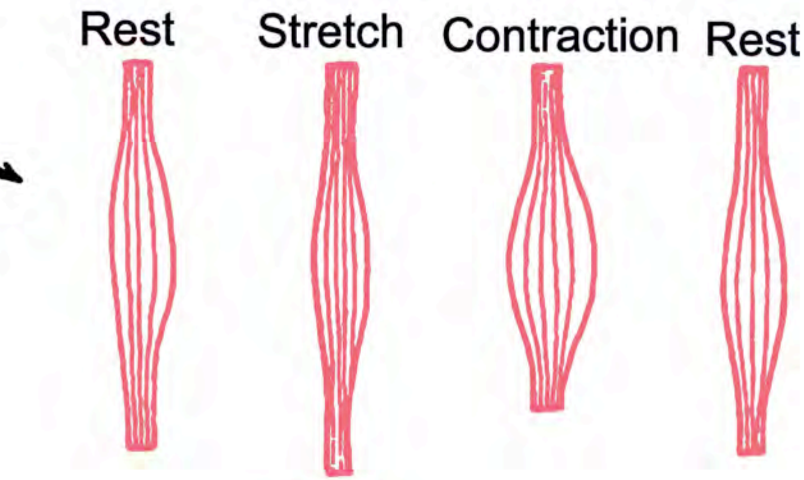
1. Stretch (Ia, myotactic)
2. Golgi tendon organ (GTO, Ib, inverse myotactic)
3. FRA (flexion reflex afferent)
4. Recurrent inhibition (Renshaw Cells)



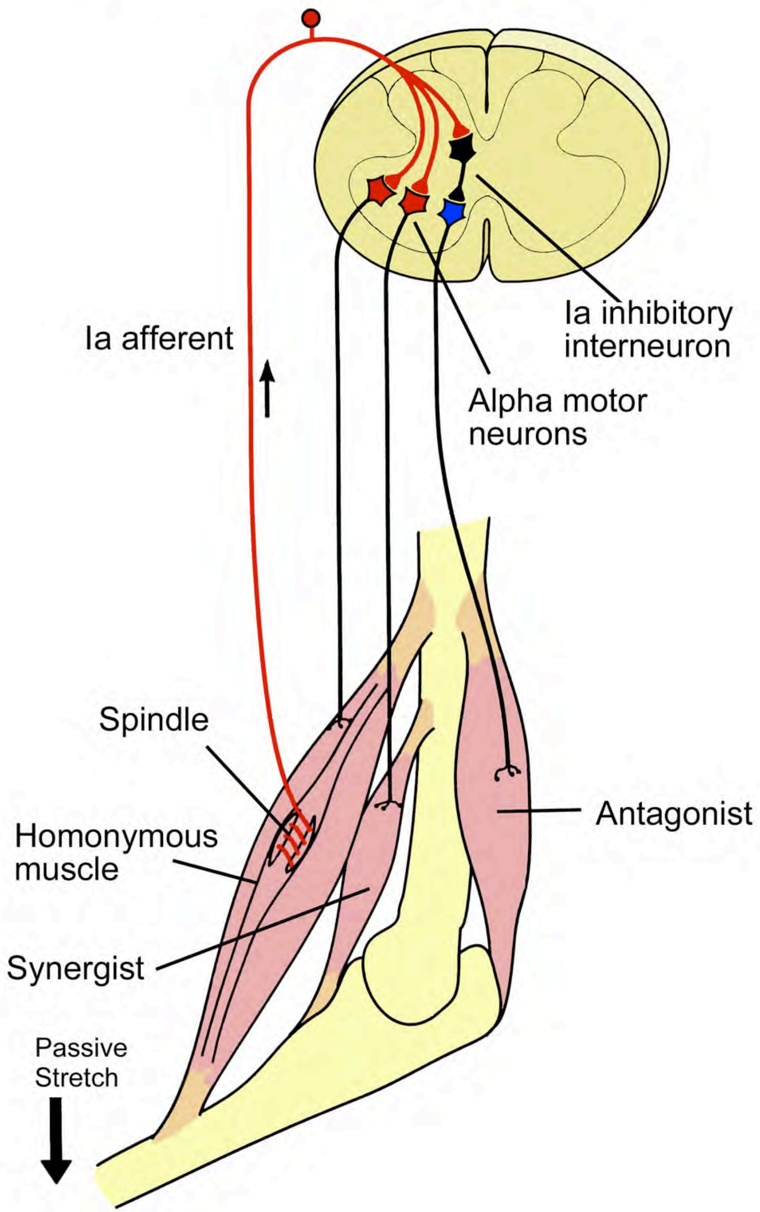
Axonal diameter is a basis for naming reflexes

Ia Stretch Reflex





Ia stretch reflex circuit



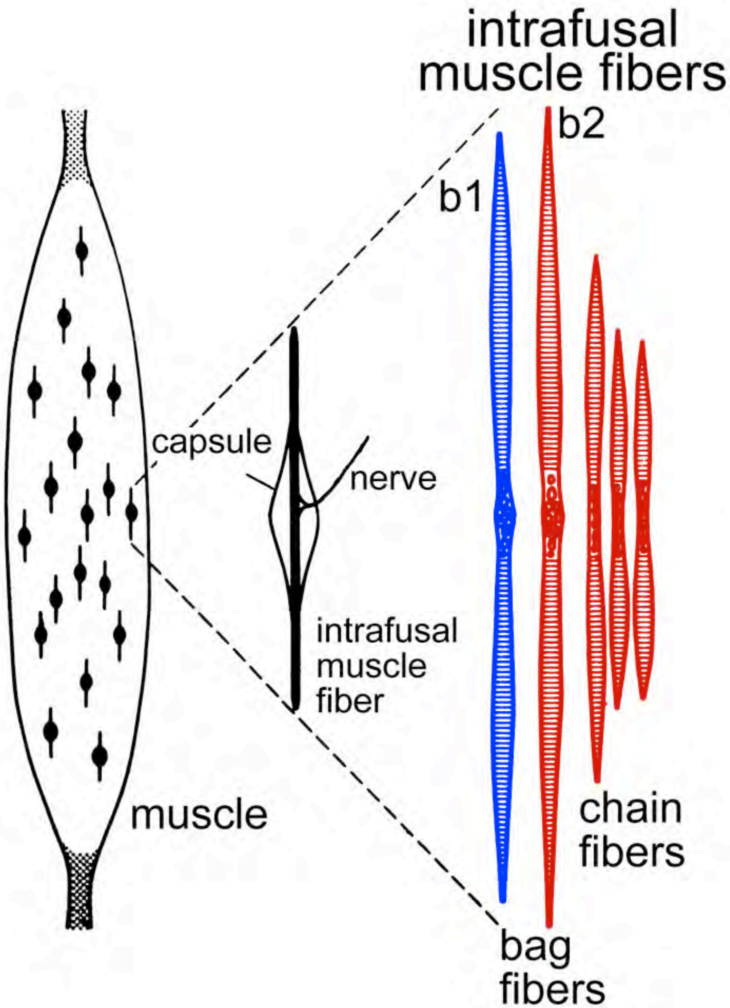
Maximal convergence and divergence, and monosynaptic nature make it very powerful circuit, but still represents only small fraction of synapses to motor neuron:

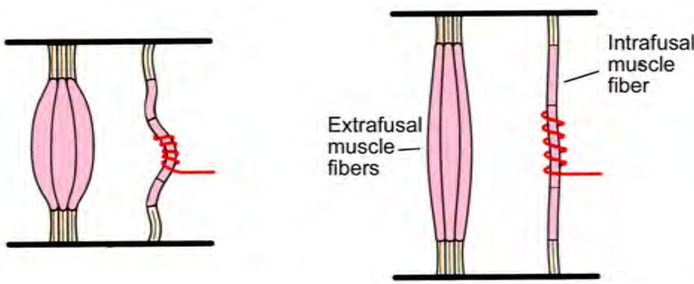
•Ia makes 10 synapses on MTN

•1 MTN gets 500-1000 Ia synapses, about 1-2% of total synapses on MTN.

Feedback to alphas not gammas to avoid positive feedback loop (?), but what about betas?

Muscle Spindle Structure



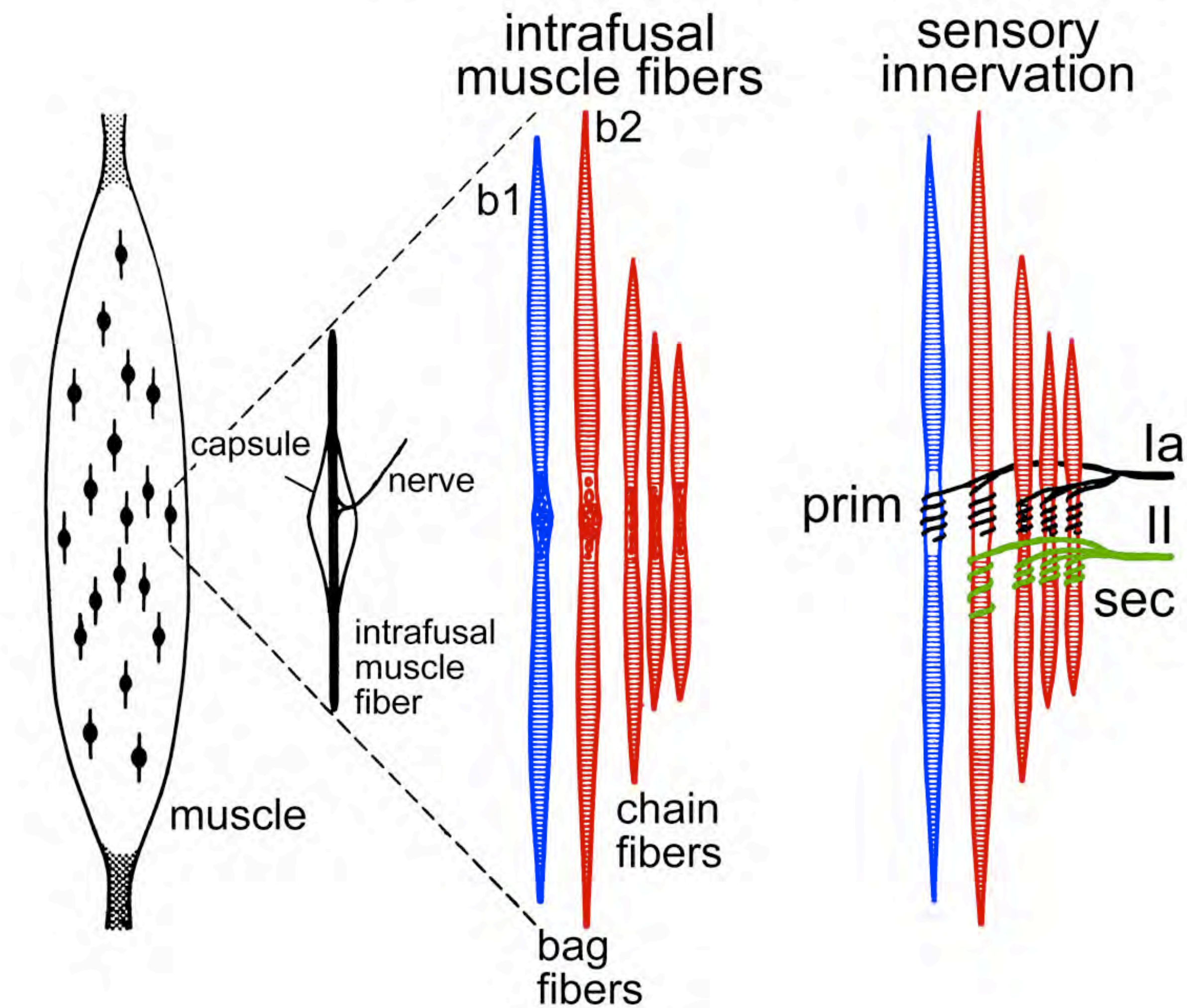


Intra and extra fusal fibers are in parallel, making spindle sensitive to muscle length.

$F=k(x-x_0)$

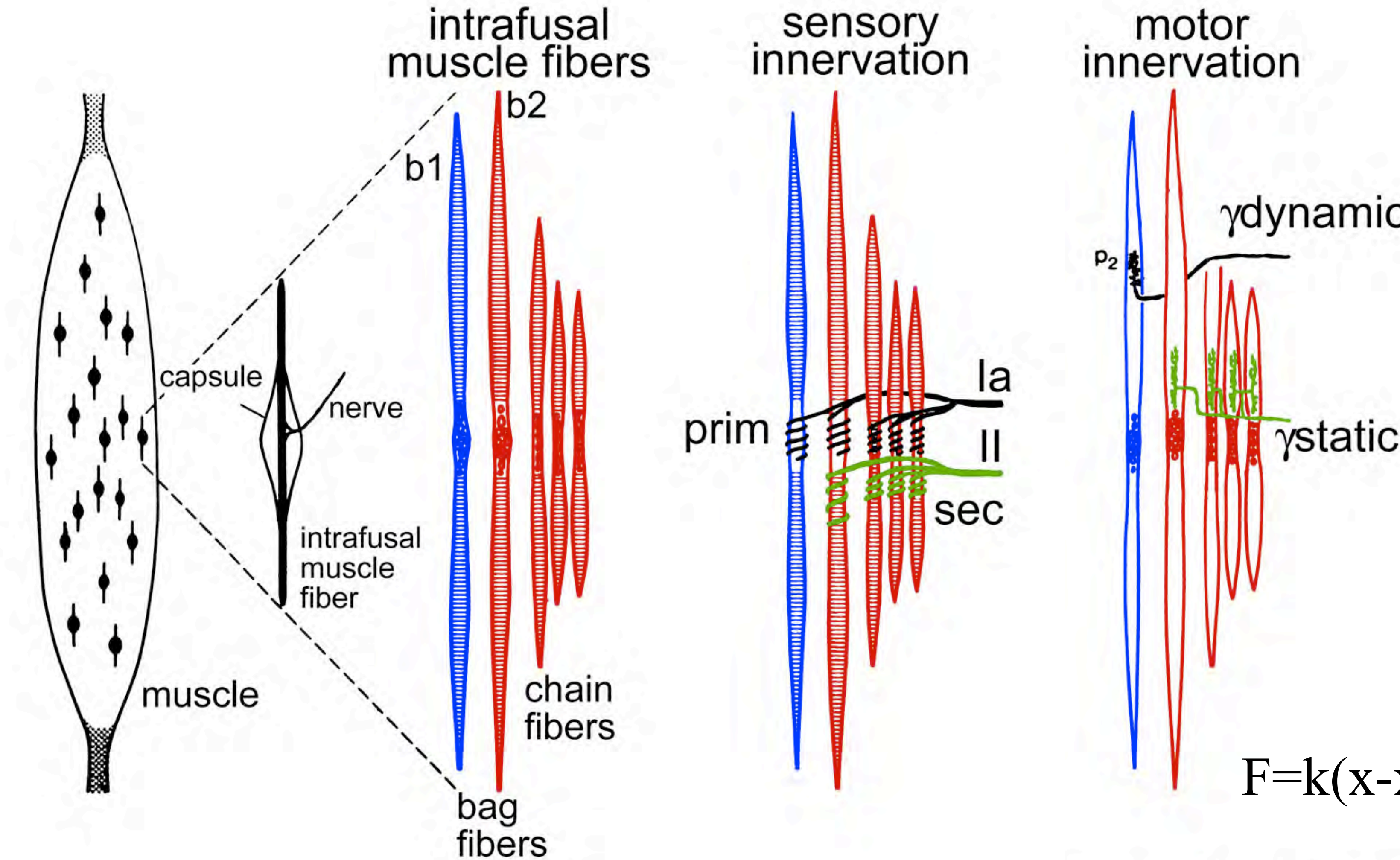
Emonet-Denand et al., 1980

Muscle Spindle Structure



Emonet-Denand et al., 1980

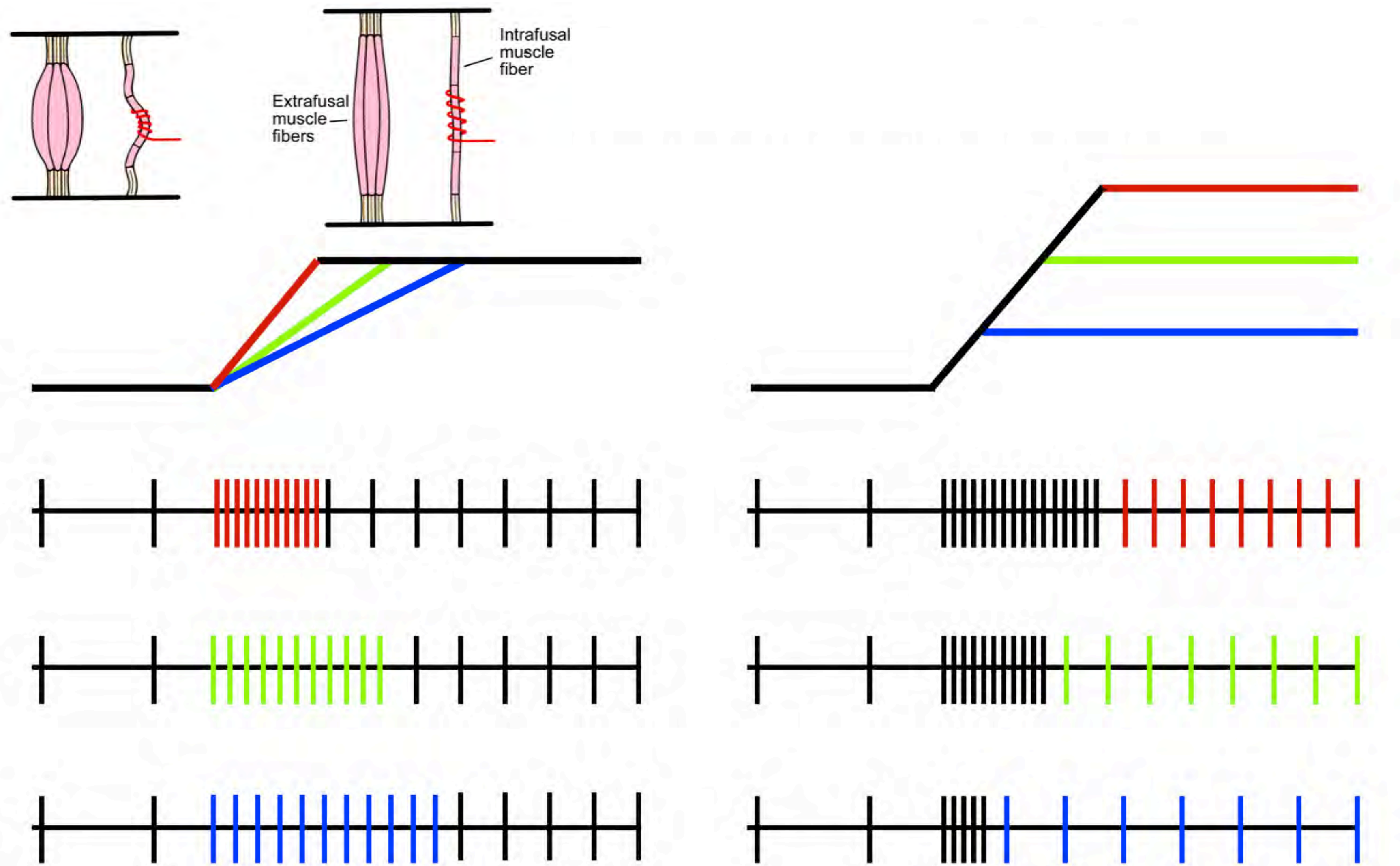
Muscle Spindle Structure

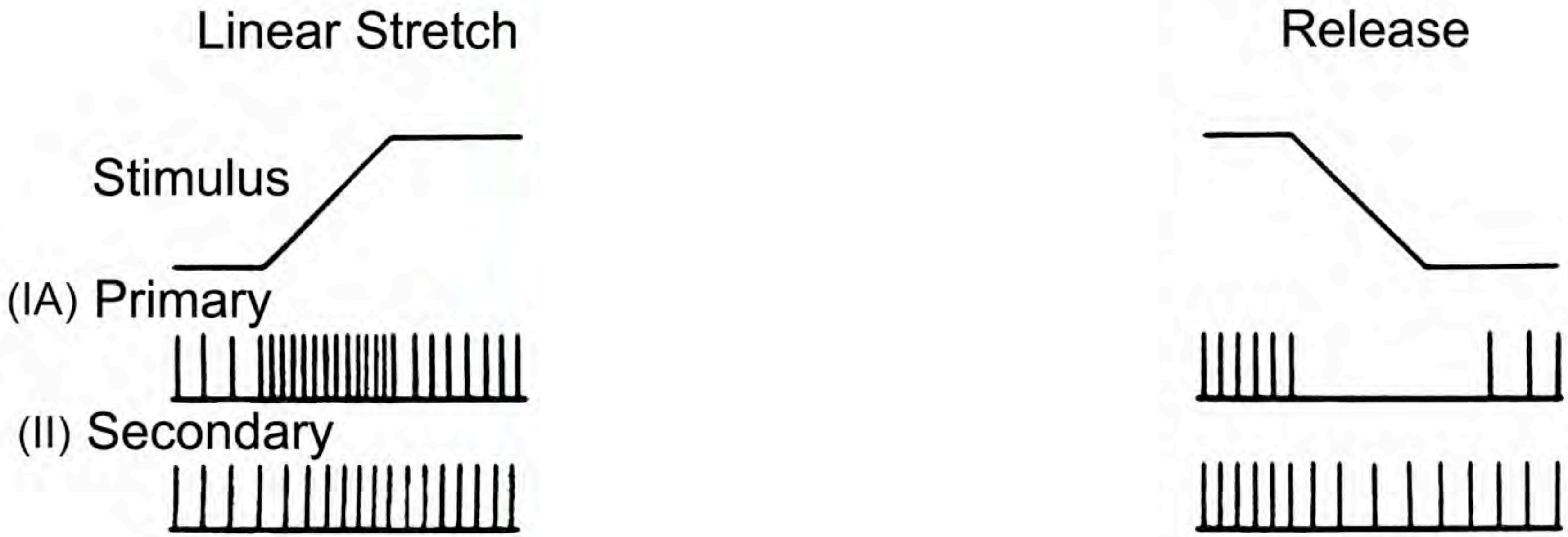


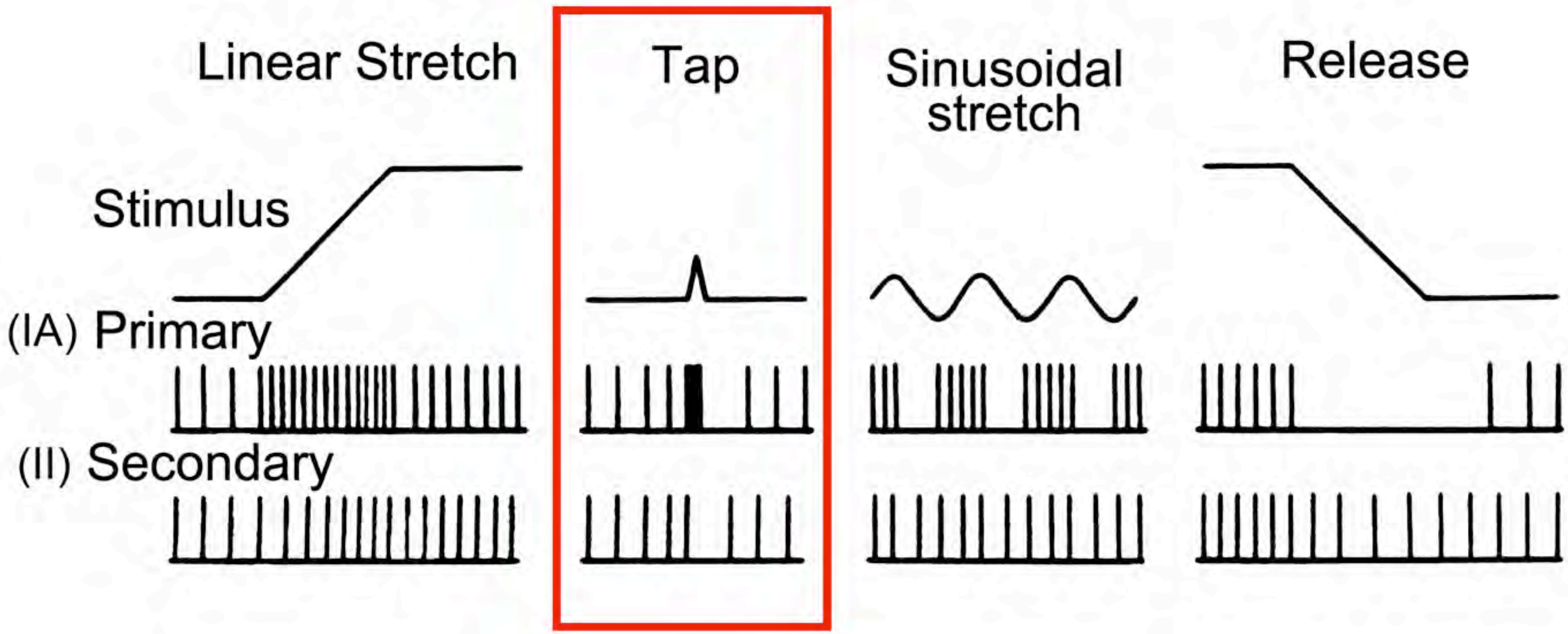
$F=k(x-x_0)$

Emonet-Denand et al., 1980

Response of Ia afferents to different stretches

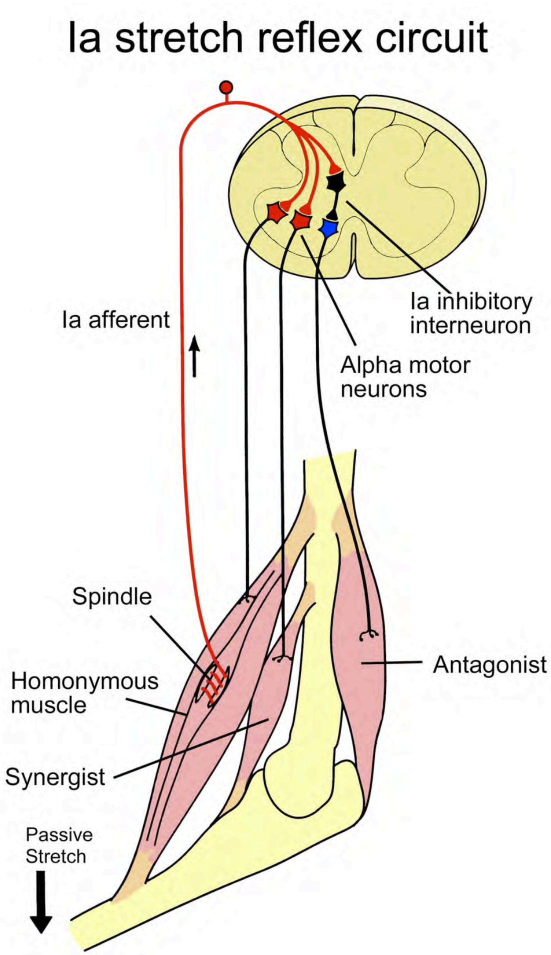



Linear Stretch
Release
Stimulus
(IA) Primary
(II) Secondary



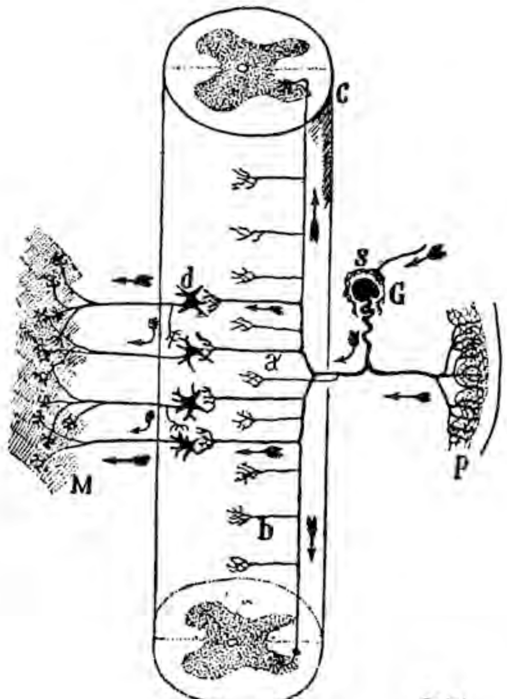
Linear Stretch
Tap
Sinusoidal stretch
Release
Stimulus
(IA) Primary
(II) Secondary

How do we know this is the pathway??

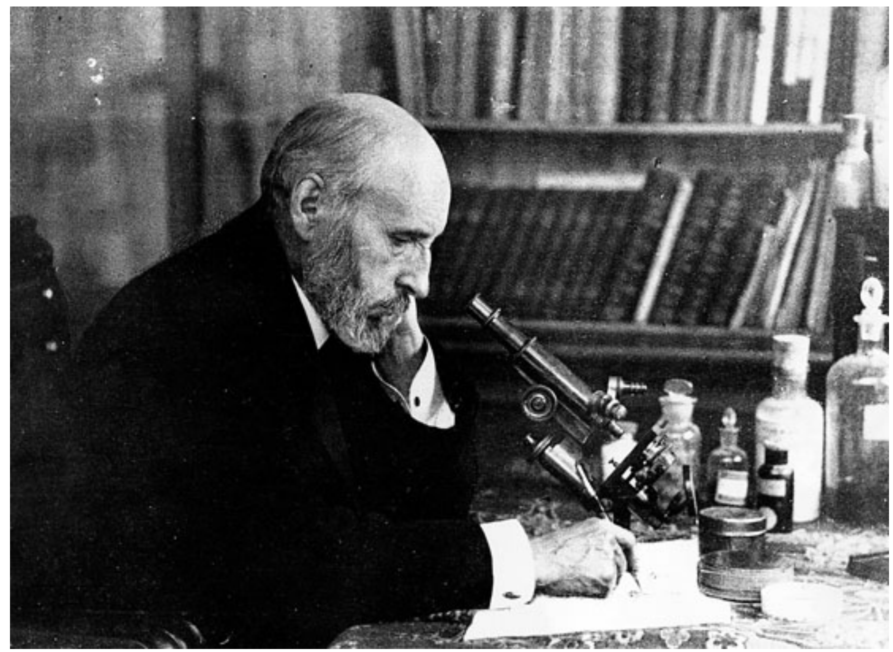


(i.e., how do we know it is the large Ia fibers?
And how do we know it is a monosynaptic pathway?)

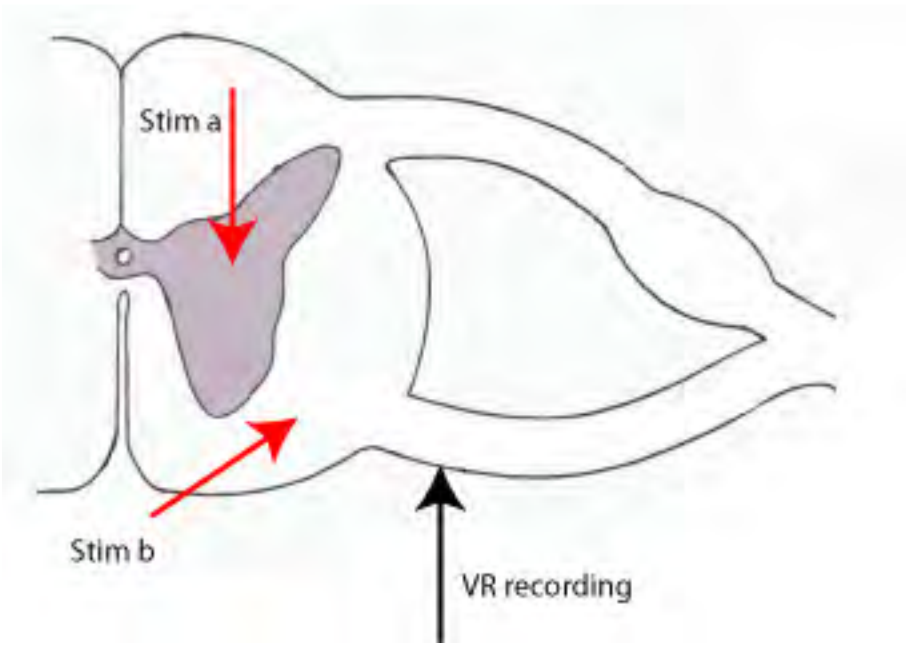
How do we know this is the pathway??

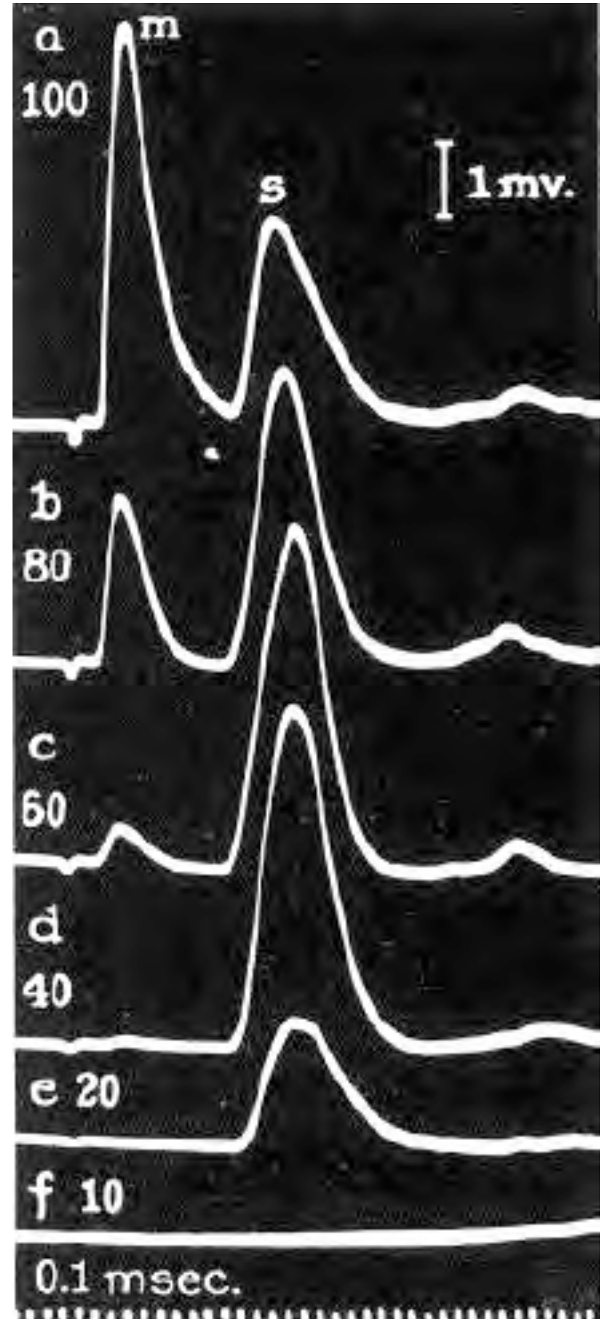


Cajal



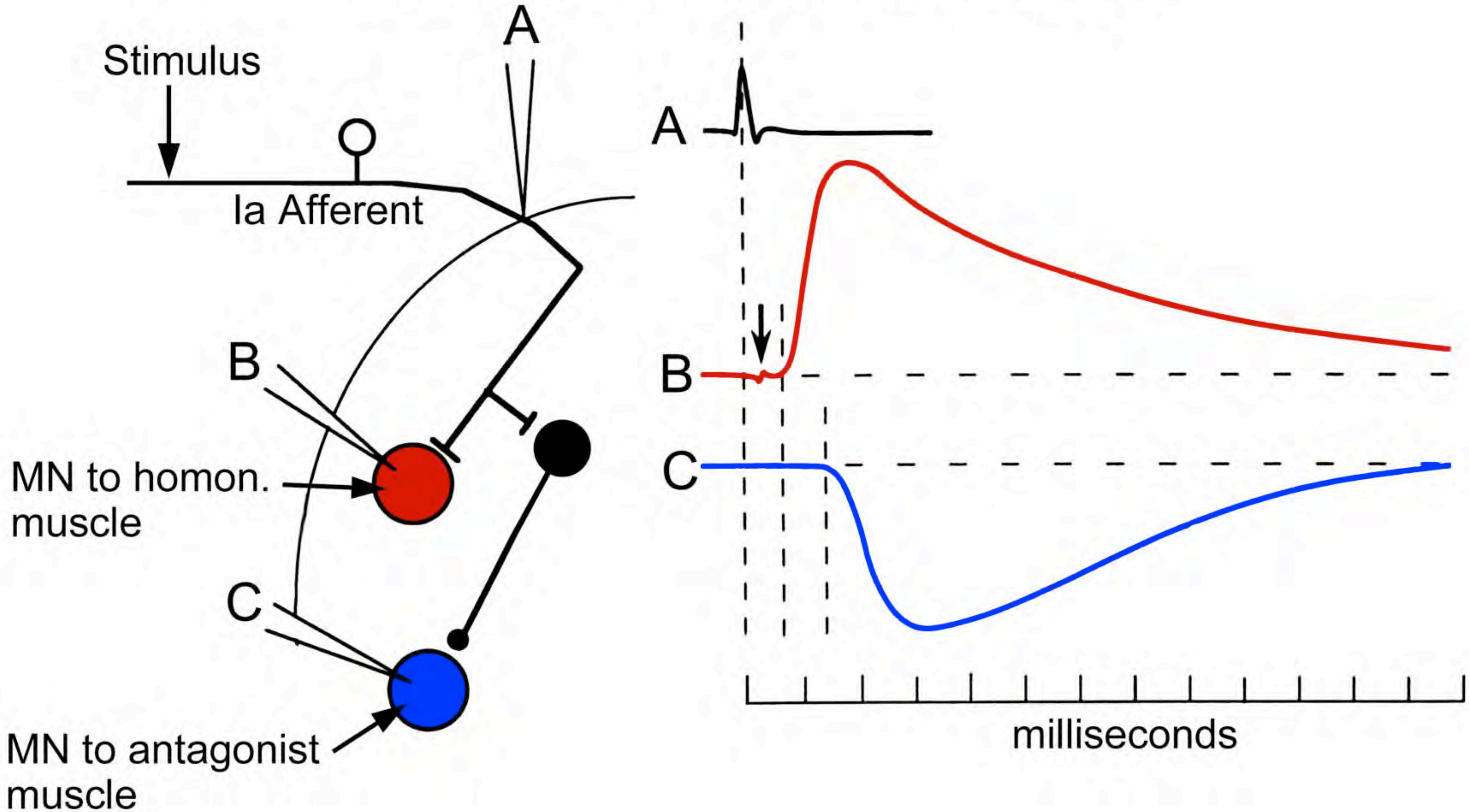
Demonstration of synaptic delay





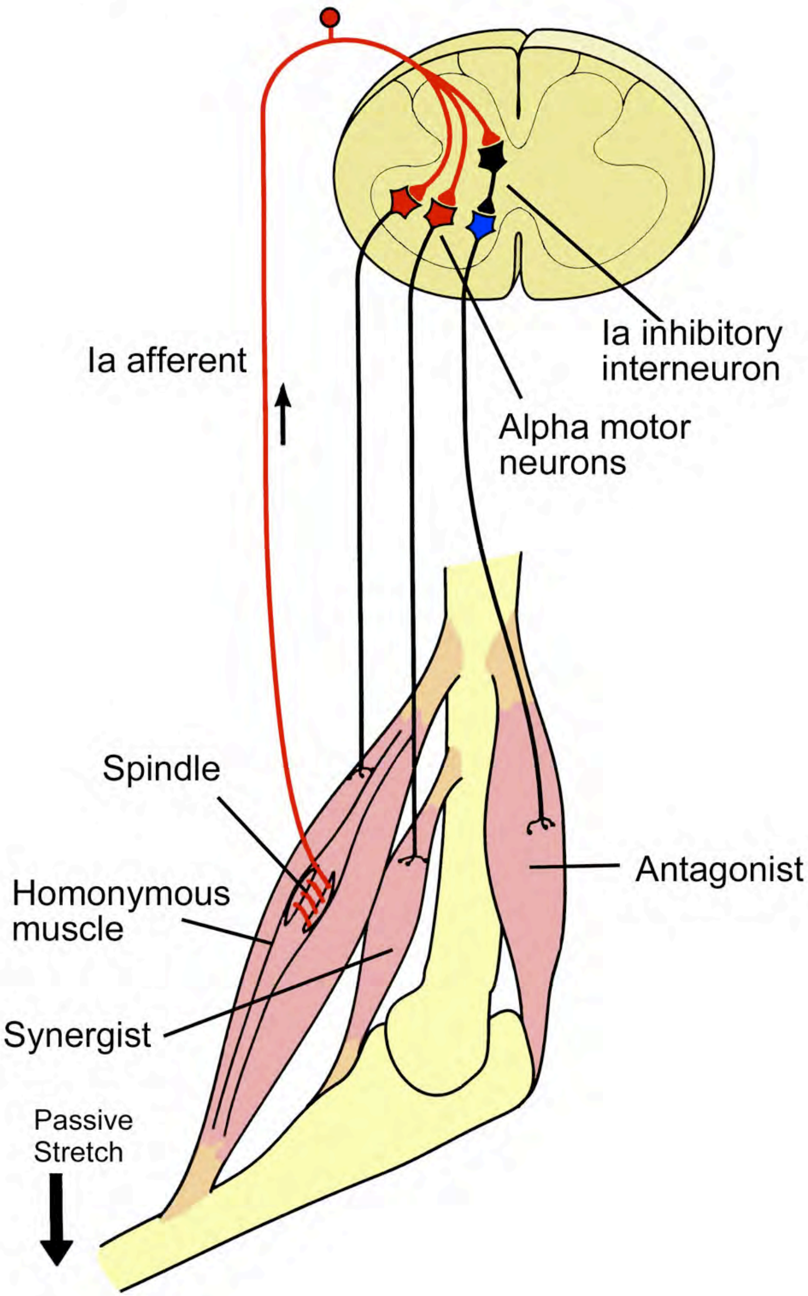
Renshaw 1940

Monosynaptic nature of Ia reflex arc



Burke. 1990

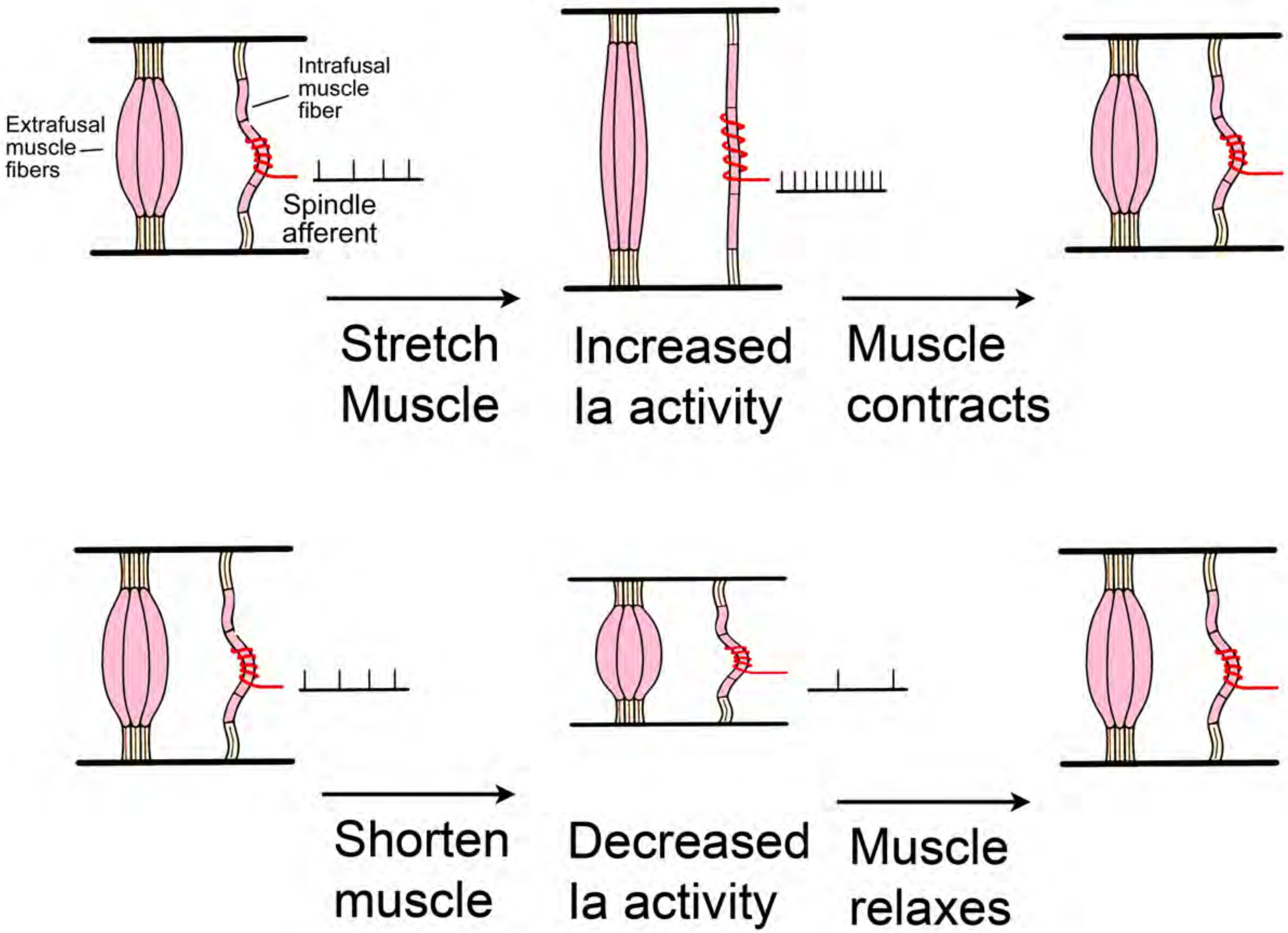
Ia stretch reflex circuit

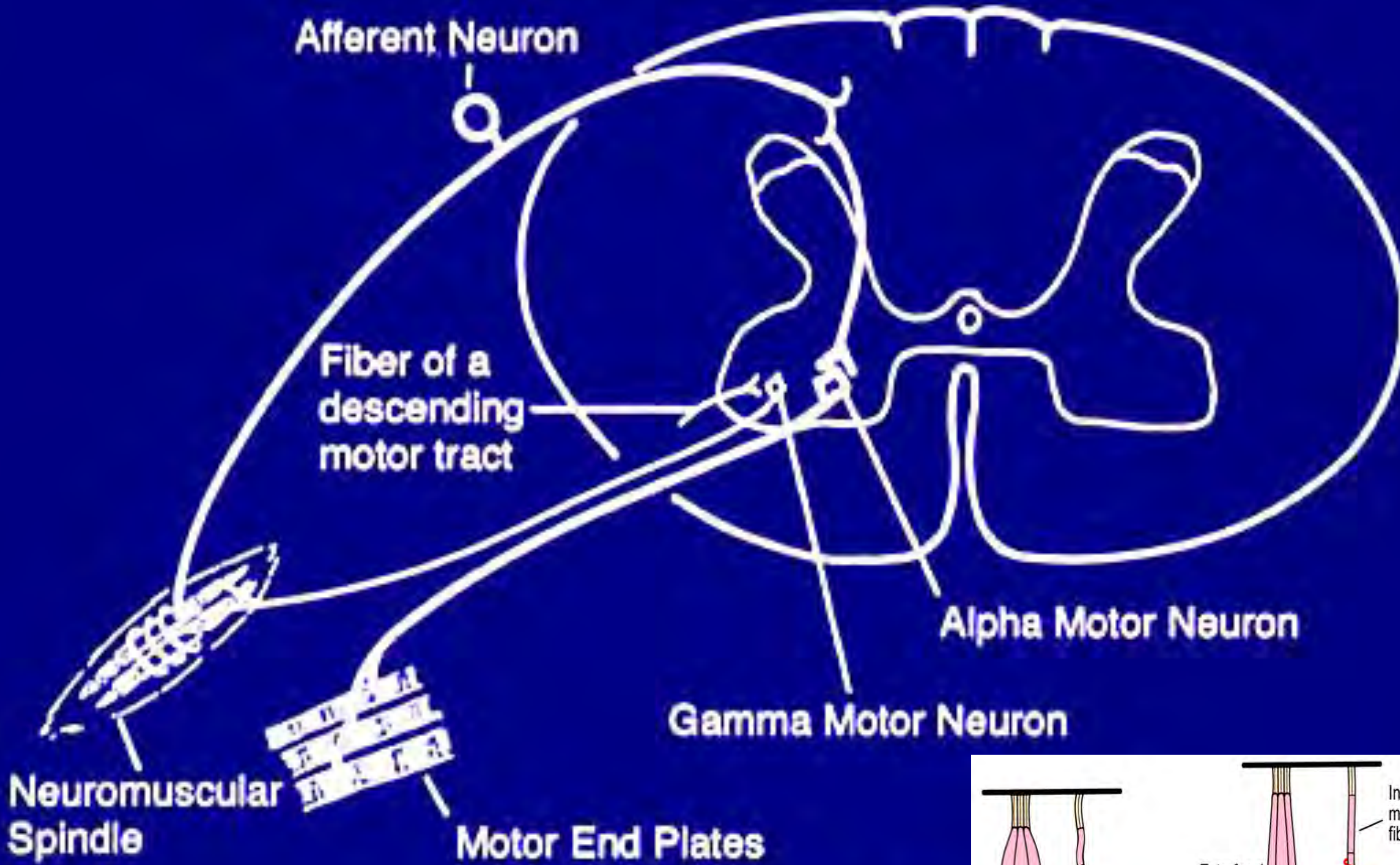


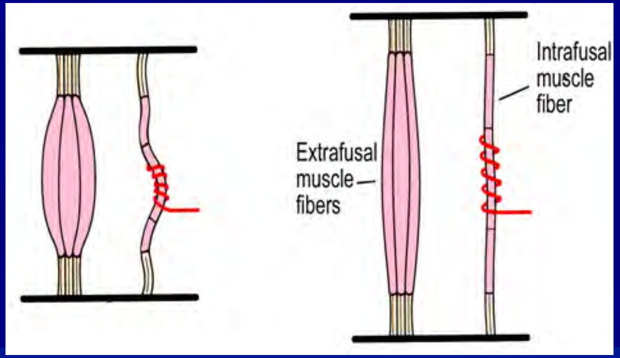
Ia reflex circuit acts:
1. to coordinate agonist / antagonist muscle pairs

2. as a length servo mechanism.

Ia circuit act to stabilize muscle at set length

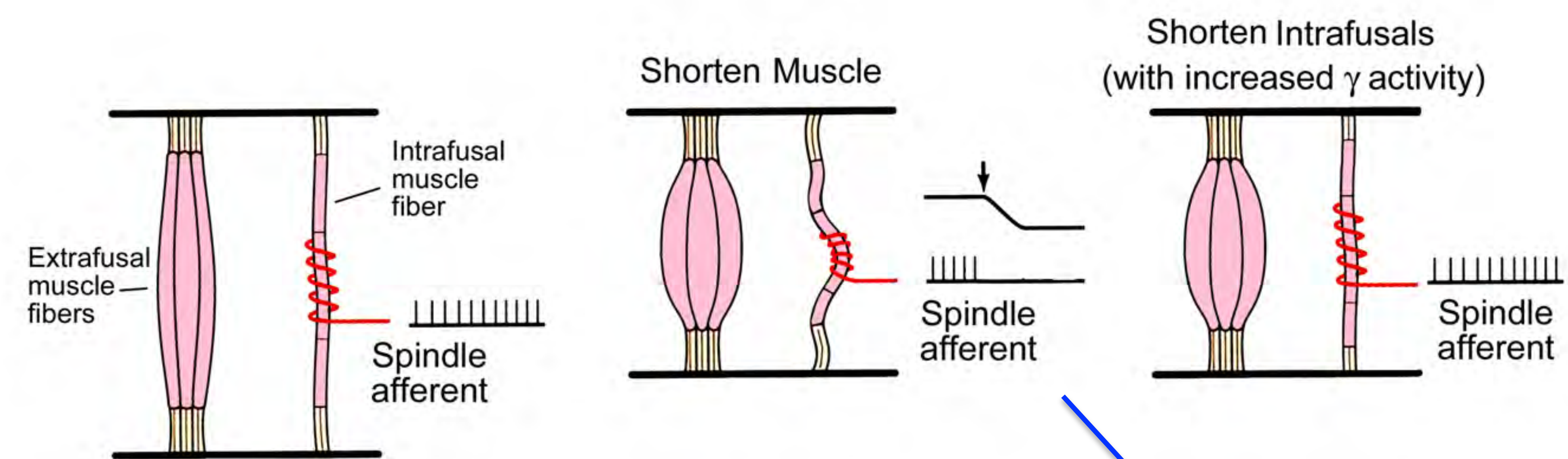






Gamma Reflex Loop

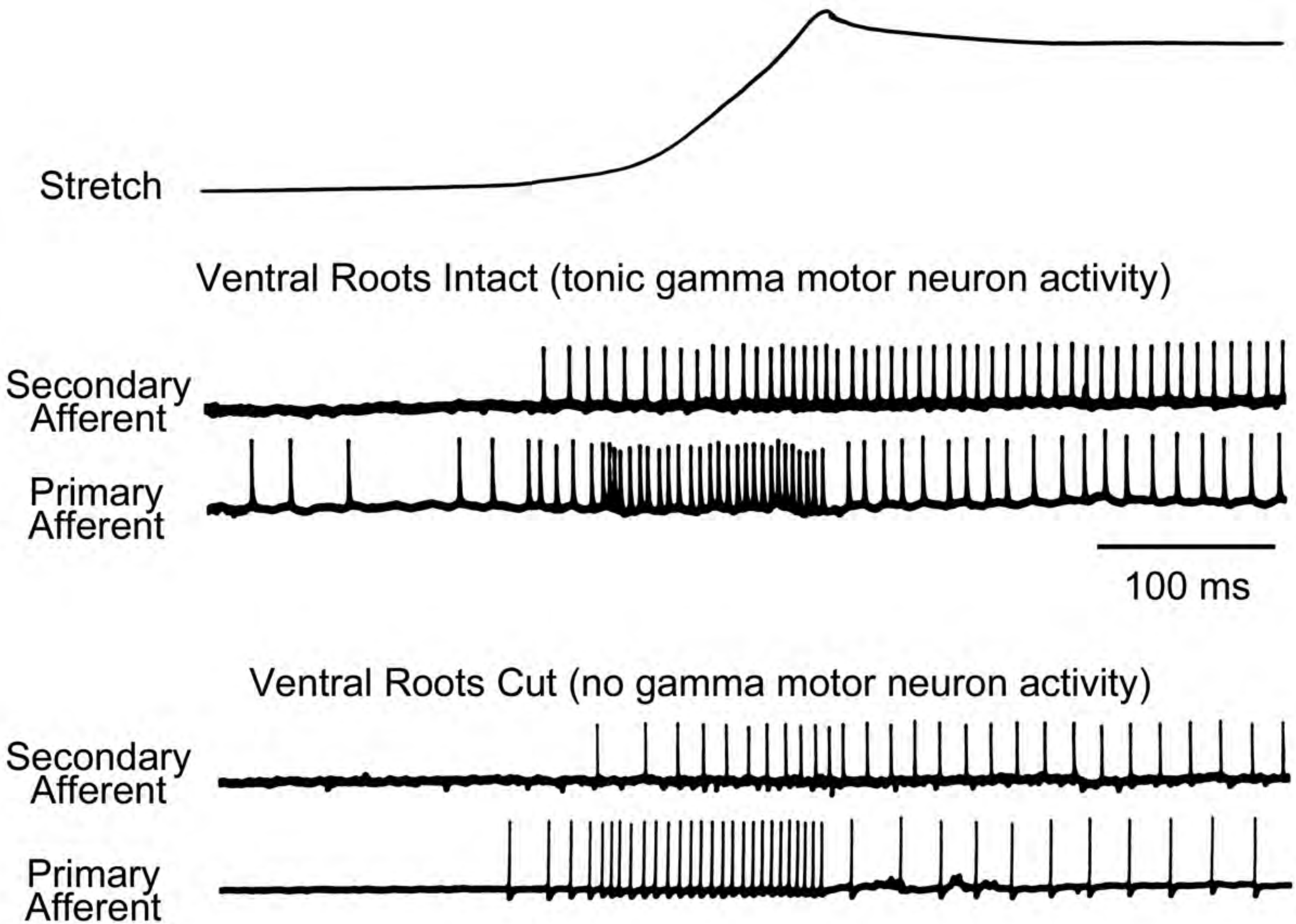
Gamma Mtns modify muscle length set point

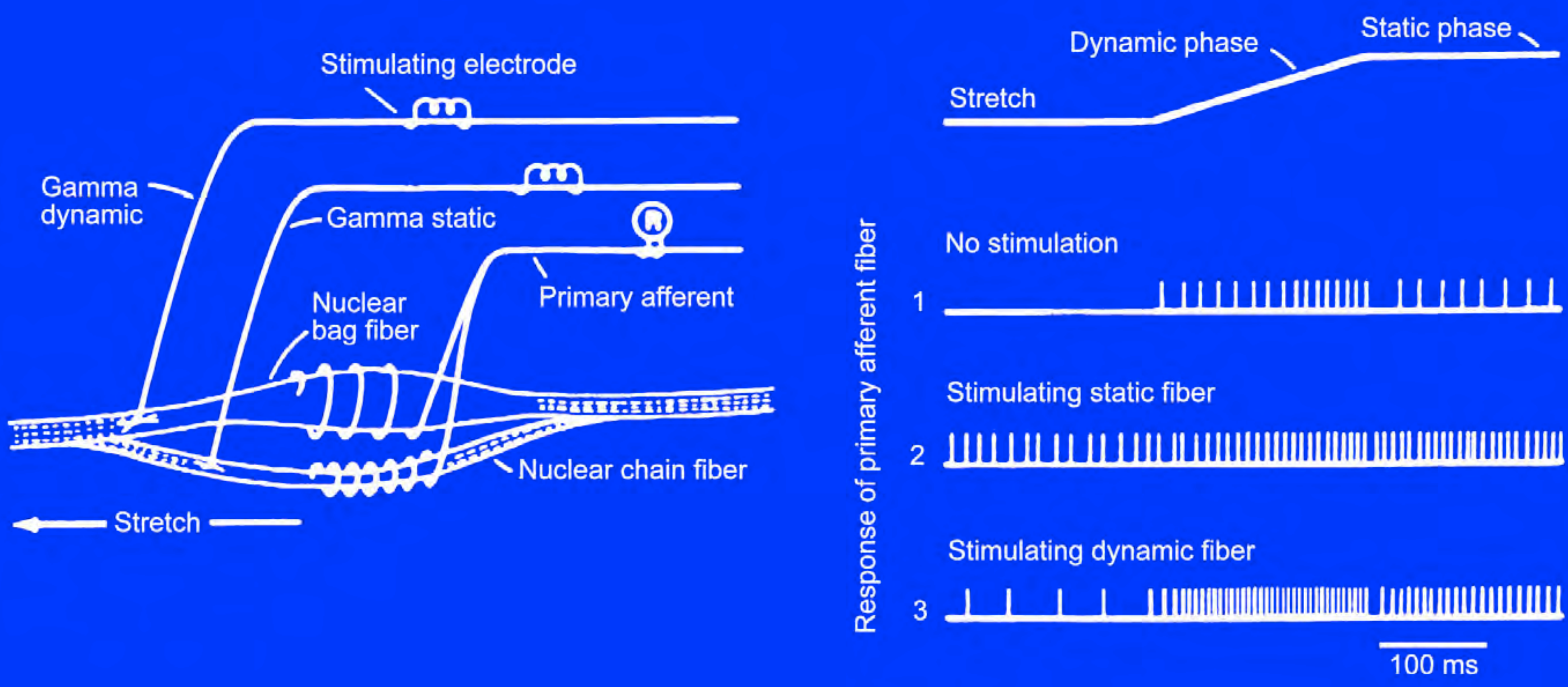


No gamma modulation

Muscle relaxes back toward original length

Gamma activity increases responses of spindle afferents

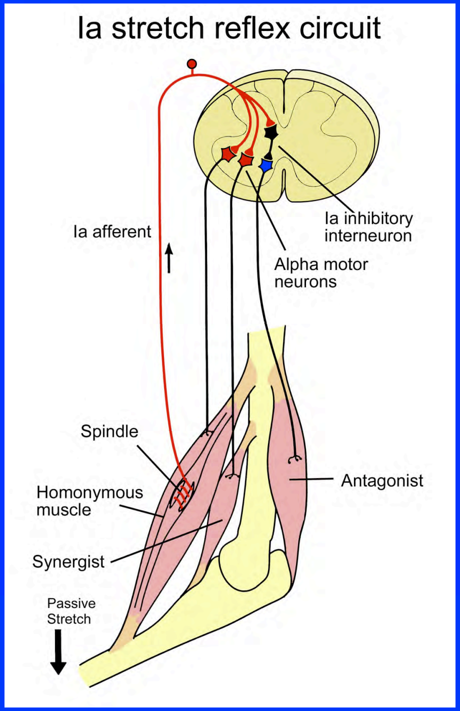


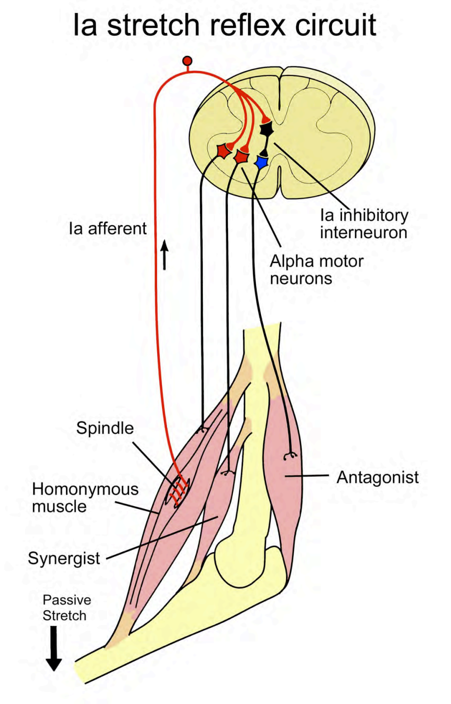


Stimulating electrode
Gamma dynamic
Gamma static
Primary afferent
Nuclear bag fiber
Nuclear chain fiber
Stretch
Dynamic phase
Static phase
Stretch
Response of primary afferent fiber
No stimulation
1
Stimulating static fiber
2
Stimulating dynamic fiber
3
100 ms

Length Servo Hypothesis of Motor Control (Merton)

Descending motor pathways produce movements by activating the γ motor neurons, which act to reset the equilibrium point for the stretch reflex.





Length Servo Hypothesis of Motor Control (Merton)

Descending motor pathways produce movements by activating the γ motor neurons, which act to reset the equilibrium point for the stretch reflex.

Predictions

1) Changes in γ motor neuron activity should precede α motor neuron activity.

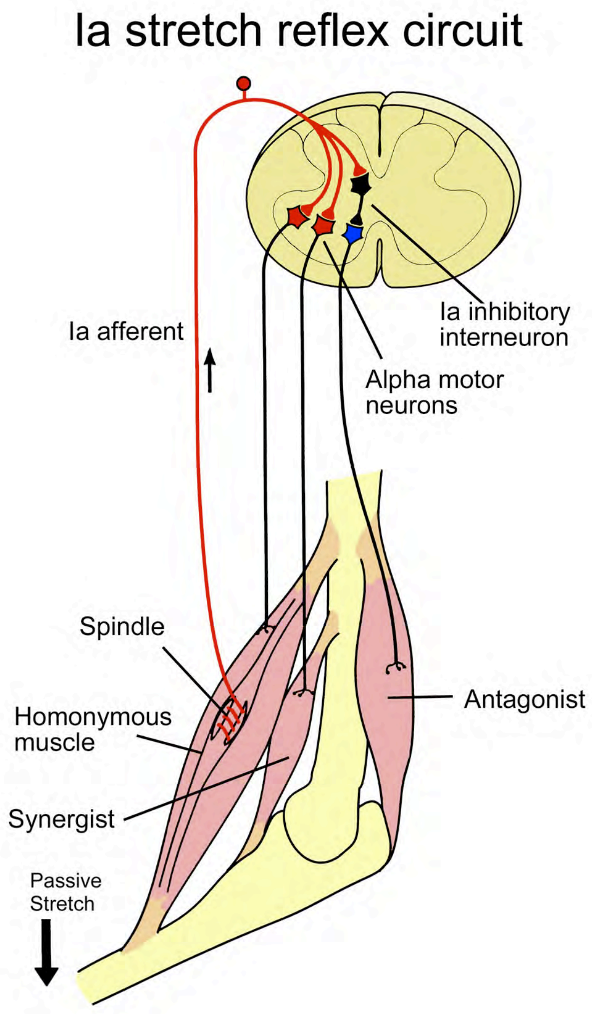
2) Changes in Ia firing should precede α motor neuron activity.

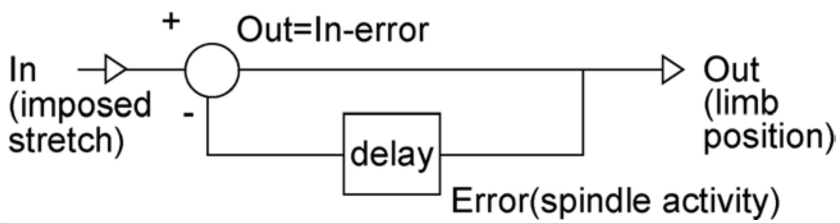
3) Movements should require intact dorsal roots.

Other problems

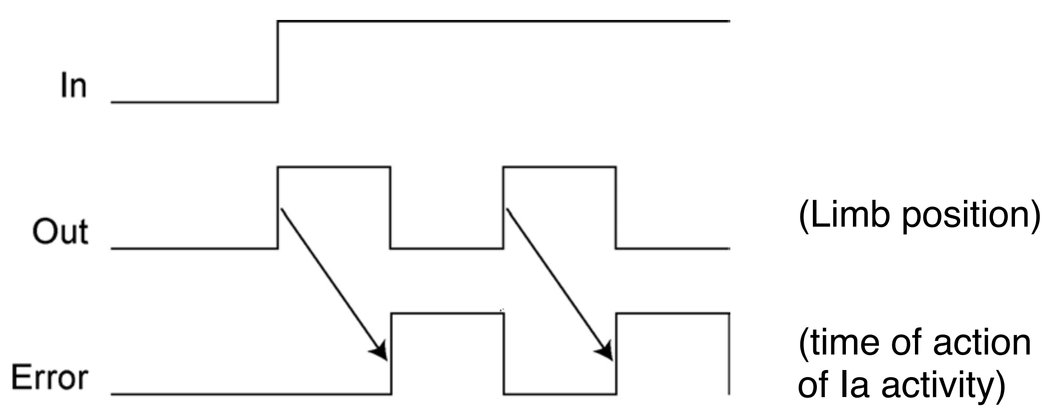
1) Insufficient gain

Stretch reflex delay may underlie clonus and tremors

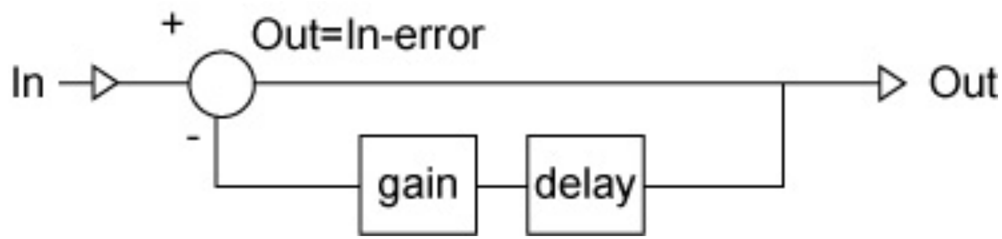


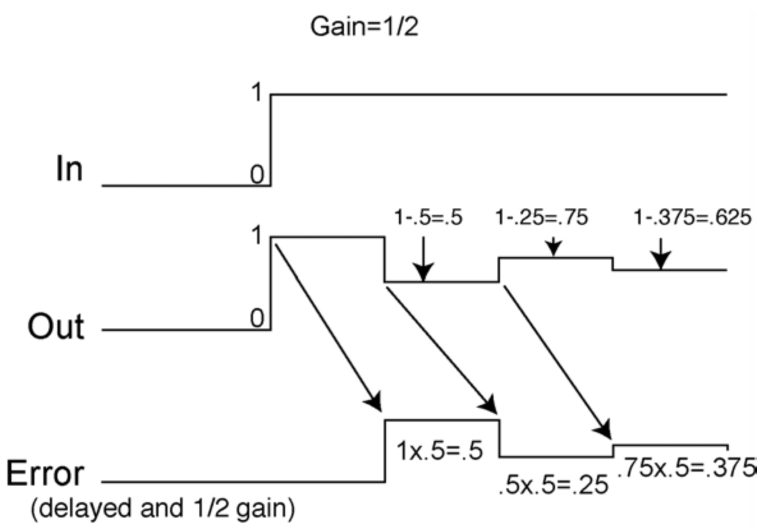


Delays allow oscillations even with steady input

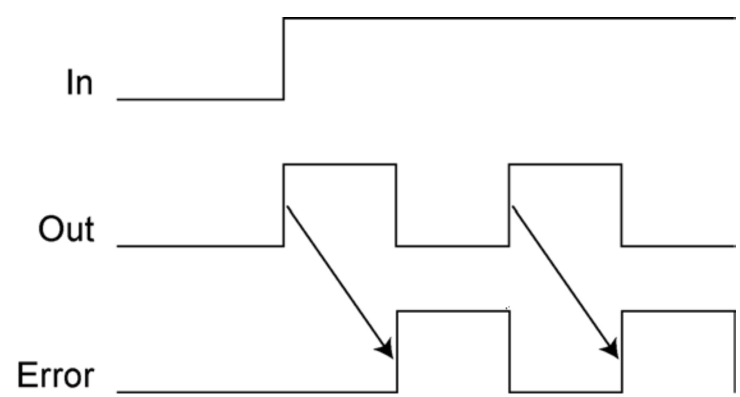


Effect of gain on stretch reflex associated tremors

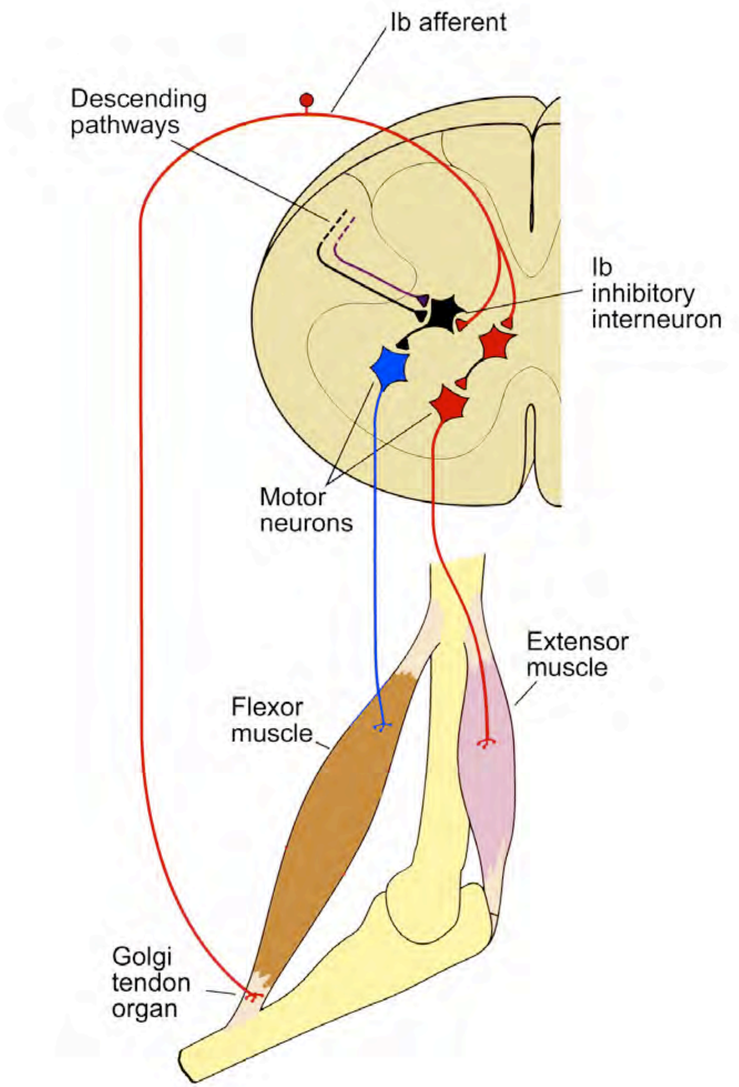




2. Reflex gain =1 ----> sustained oscillation

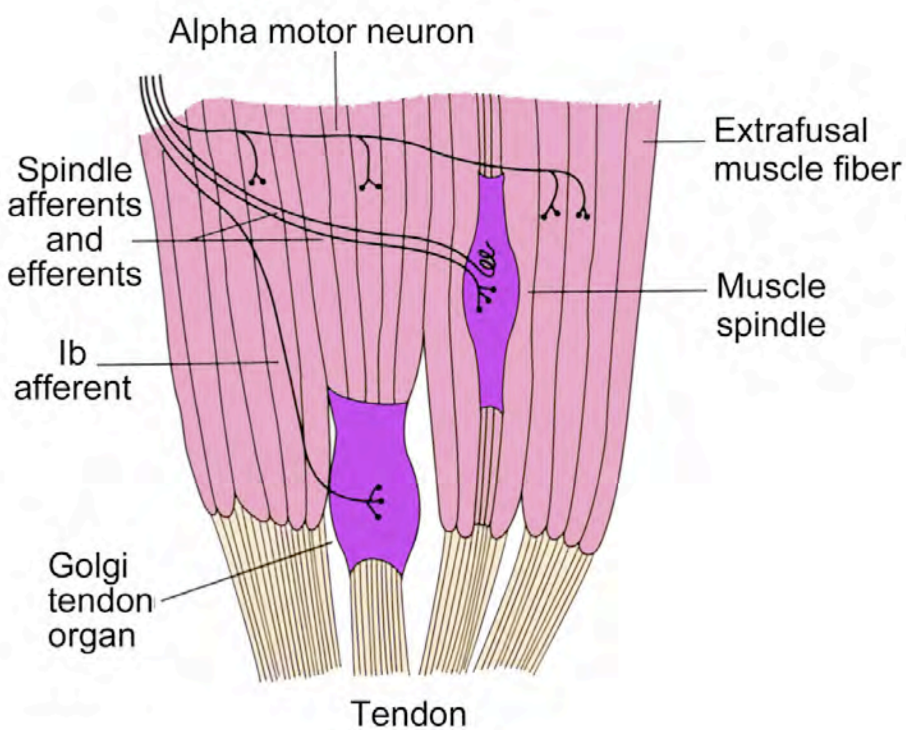


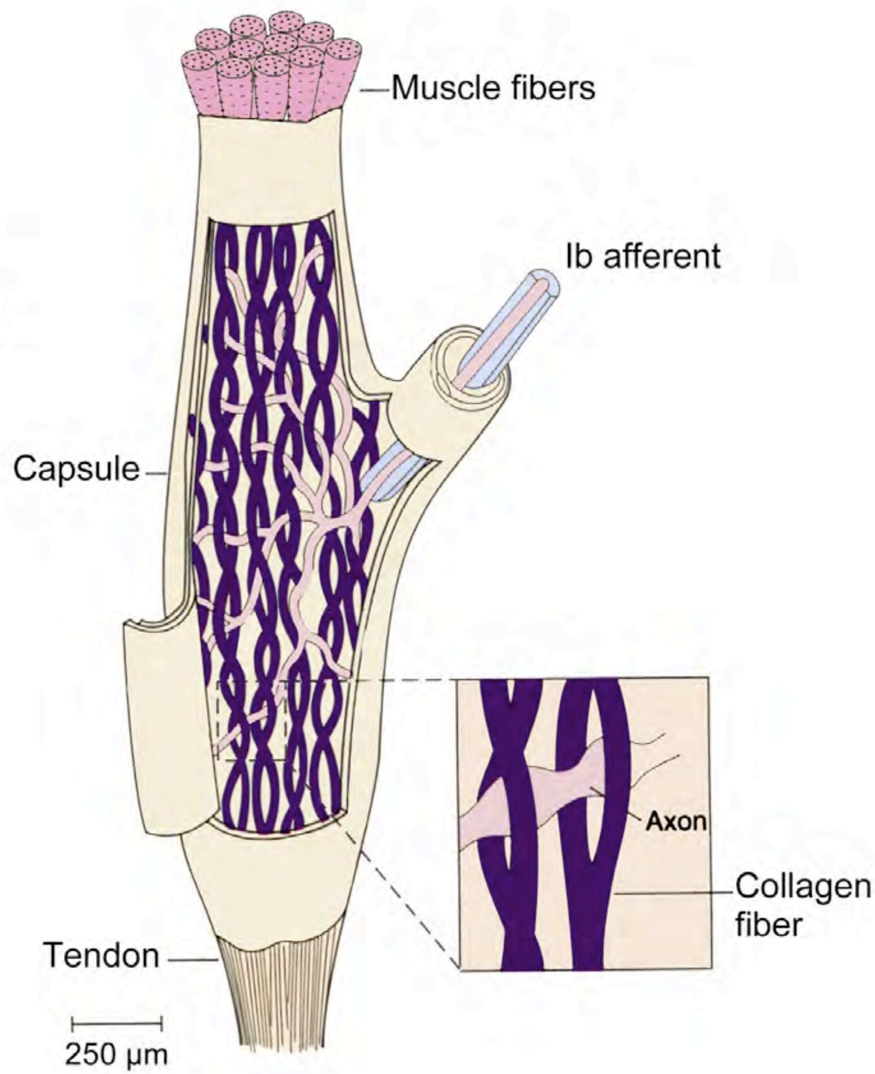
Ib reflex (inverse myotactic reflex)



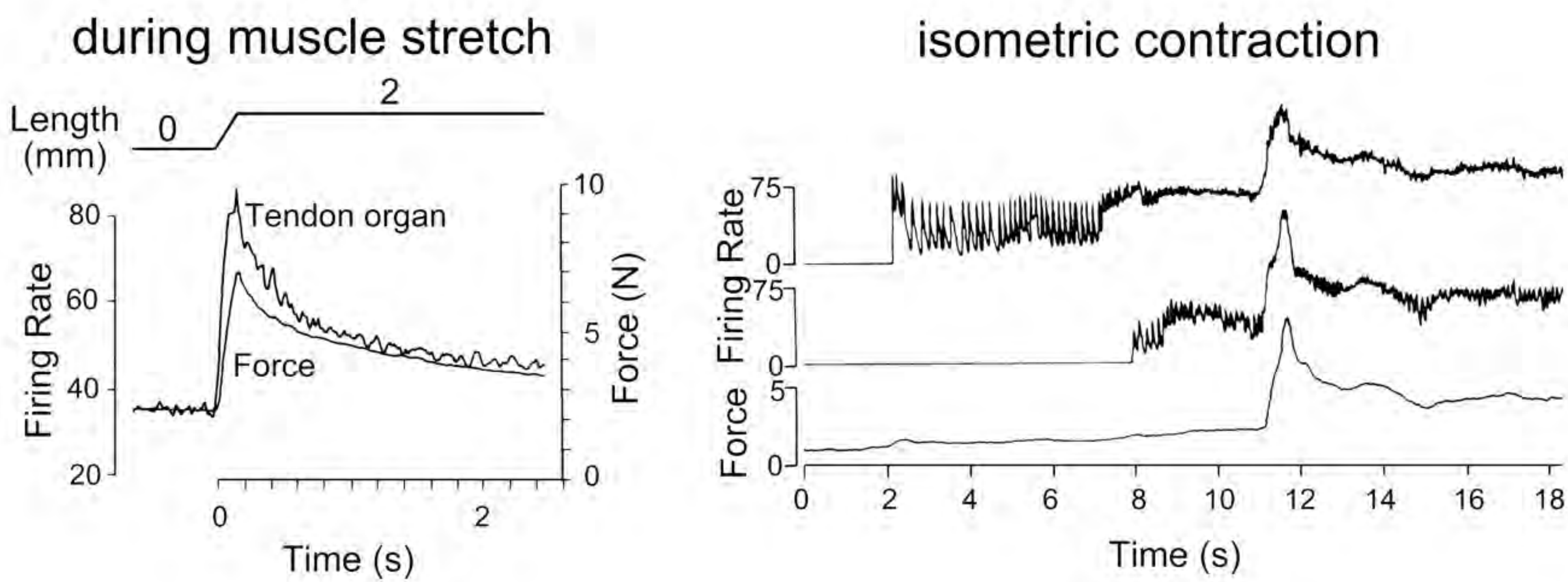
- originates in Golgi tendon organ
- regulation of force levels
- does not underlie circuit of clasp knife reflex

GTO receptor

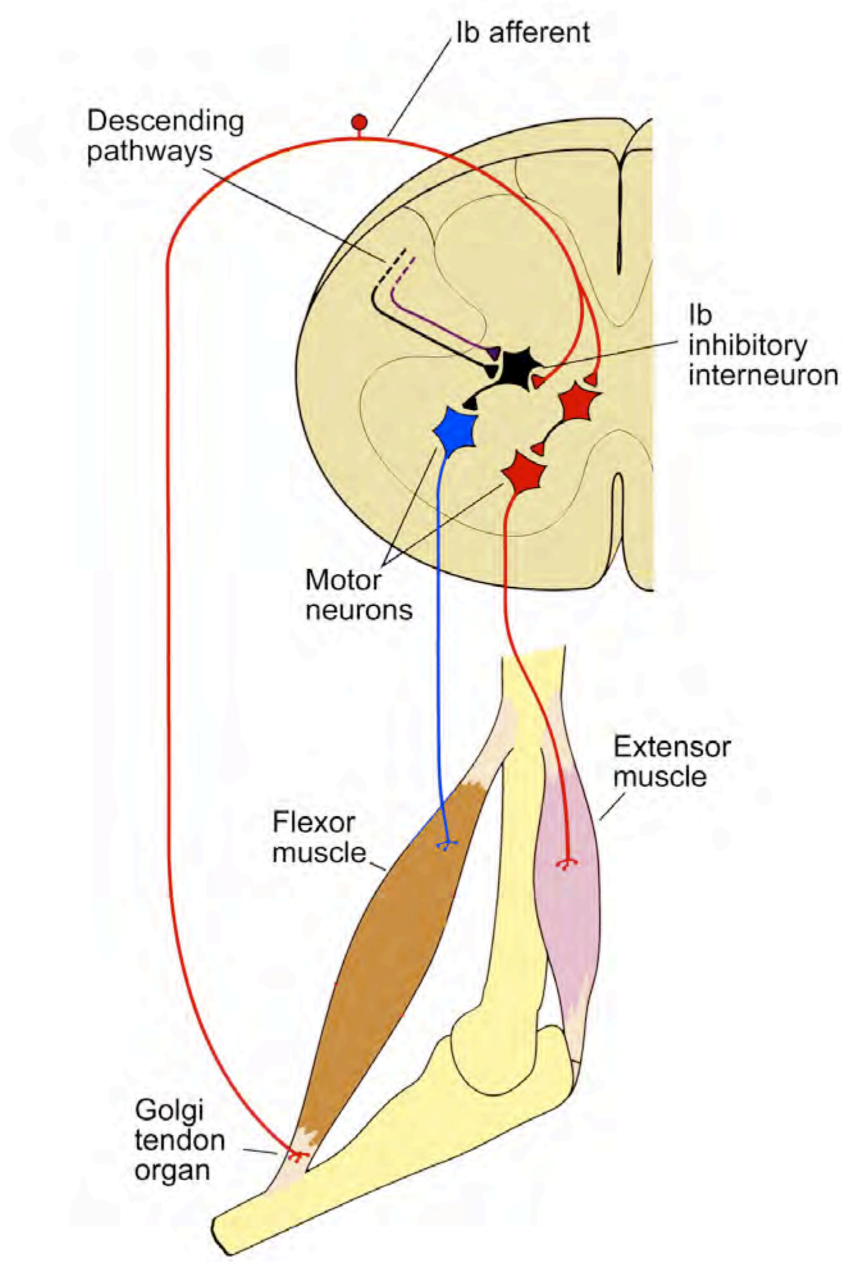




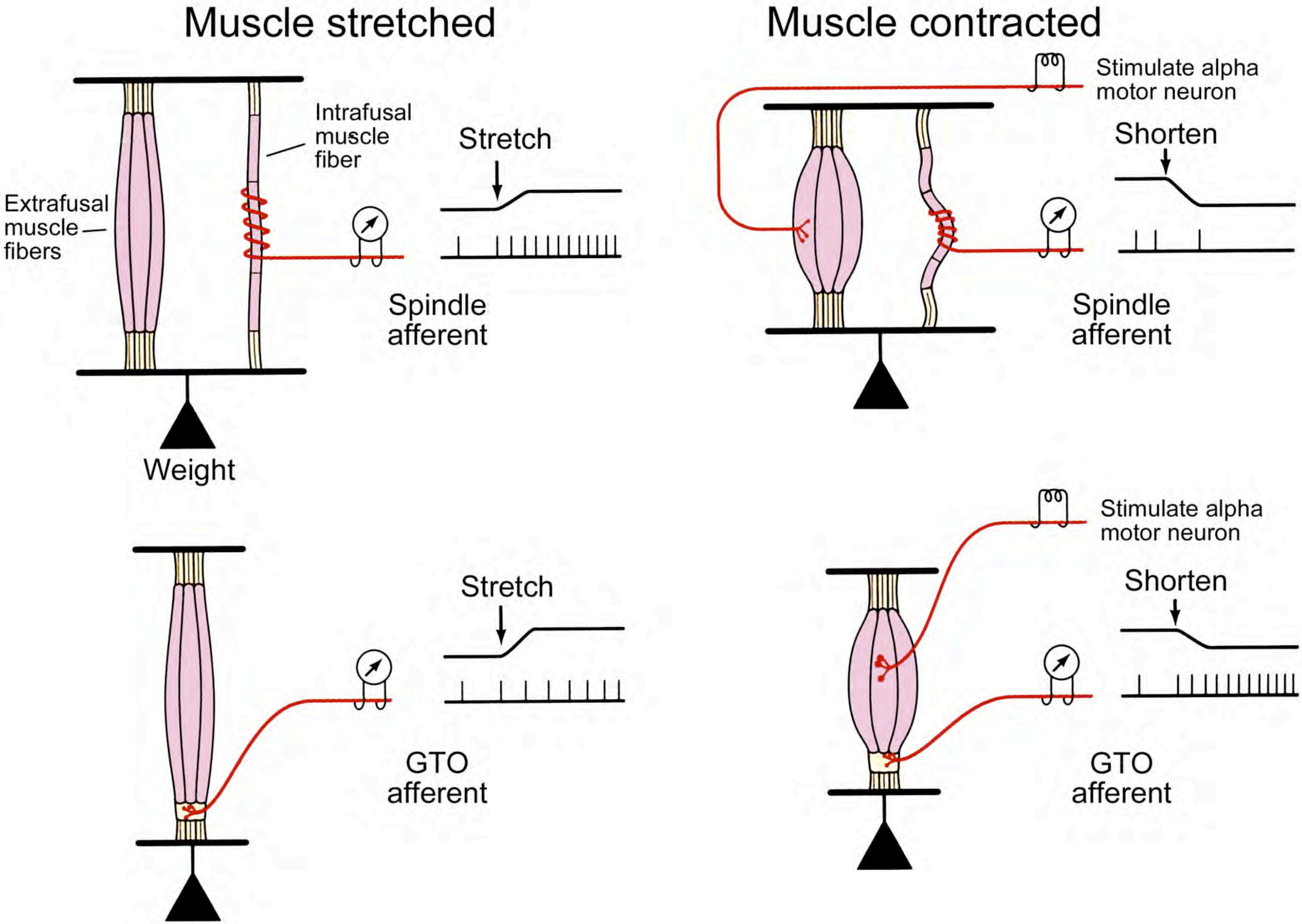
GTO afferent activity is related to muscle force



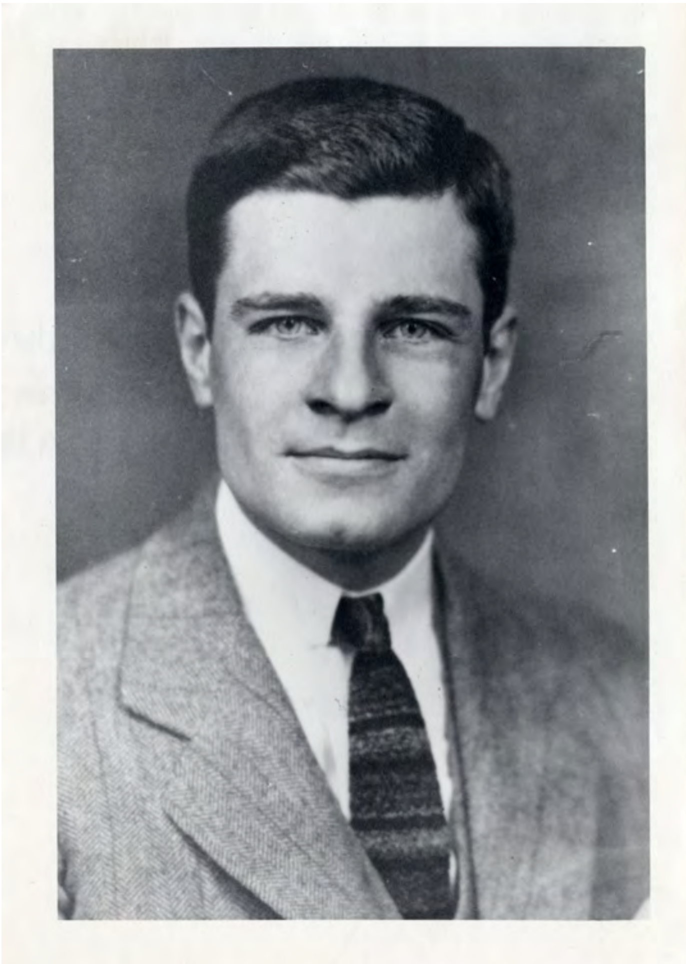
Houk et al, 1980
in Spinal and Supraspinal Mechanisms
of Voluntary Motor Control and Locomotion



Ib reflex circuit acts as a force servo mechanism

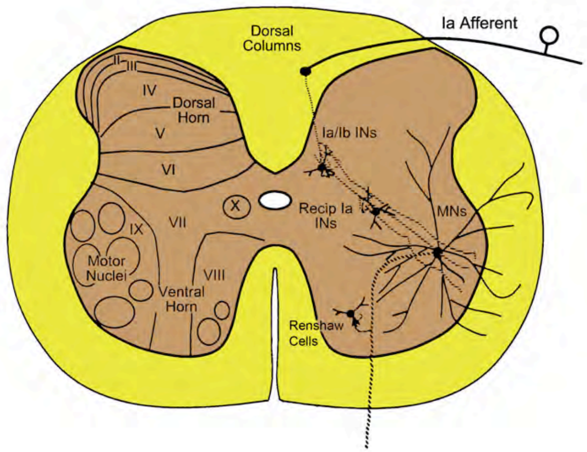

Muscle stretched
Muscle contracted
Intrafusal muscle fiber
Extrafusal muscle fibers
Stretch
Spindle afferent
Weight
Stimulate alpha motor neuron
Shorten
Spindle afferent
Stretch
GTO afferent
Stimulate alpha motor neuron
Shorten
GTO afferent

Recurrent Inhibition and Renshaw Cells

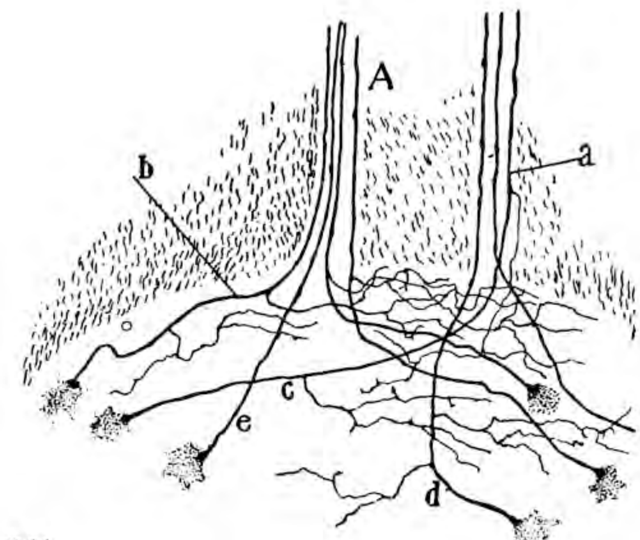


Birdsey Renshaw
(1911-1948) died of polio 3 days after onset of symptoms (contracted while taking care of family).

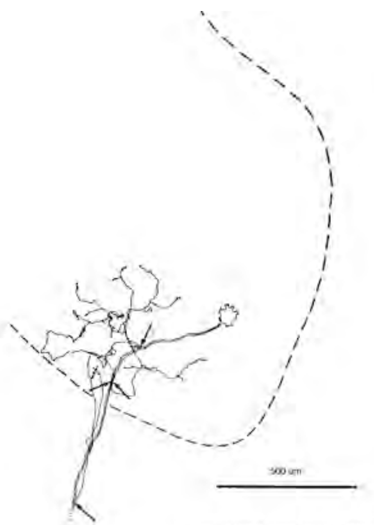
Motor neurons give off recurrent collaterals to Renshaw cells



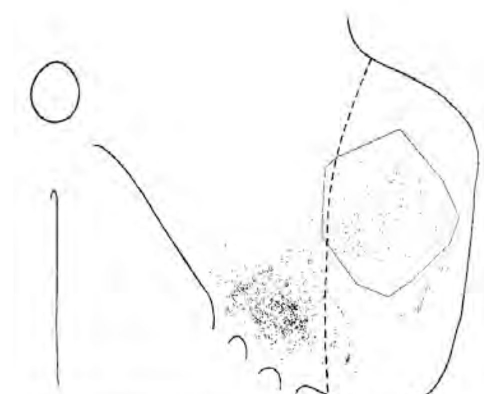
Burke, Syn Org Brain



Cajal

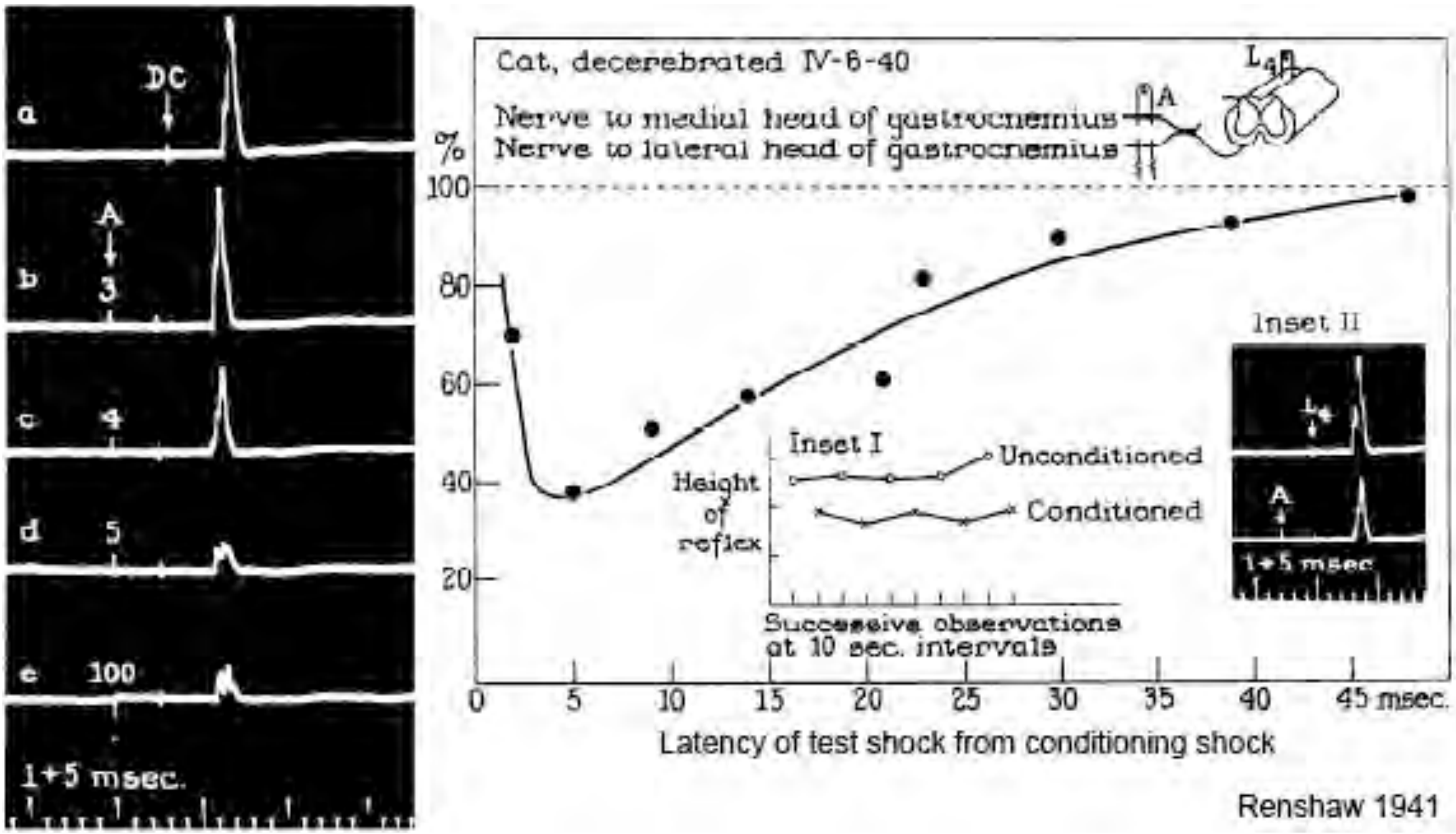


Cullheim & Kellerth (1978) J Physiol 281:285



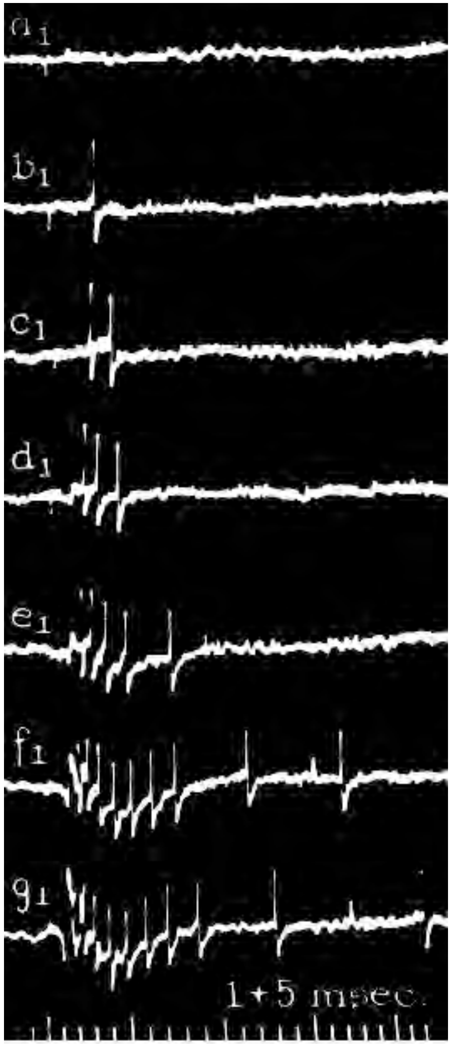
Cullheim, Kellerth, Conradi (1977) 132 1-10

Demonstrate inhibitory nature of RCs by conditioning of dorsal column stimuli



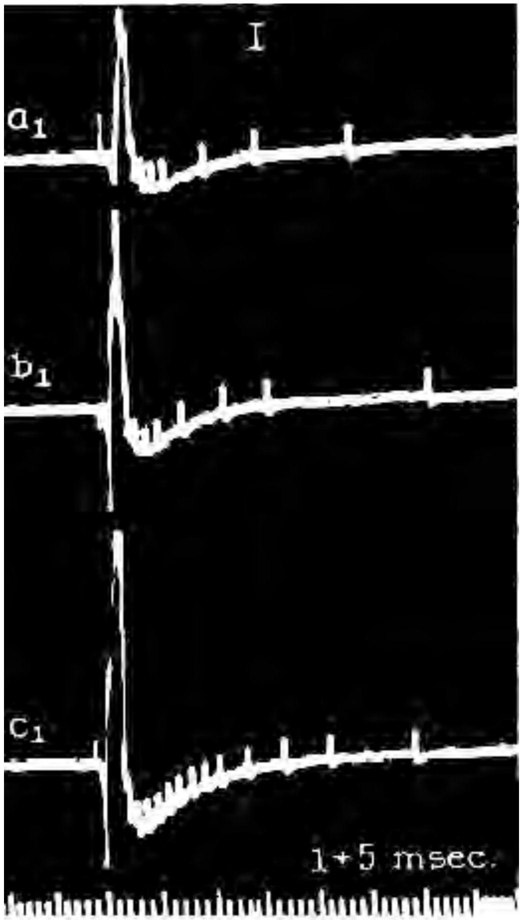
Renshaw 1941

RC response to increasing stimulus intensity



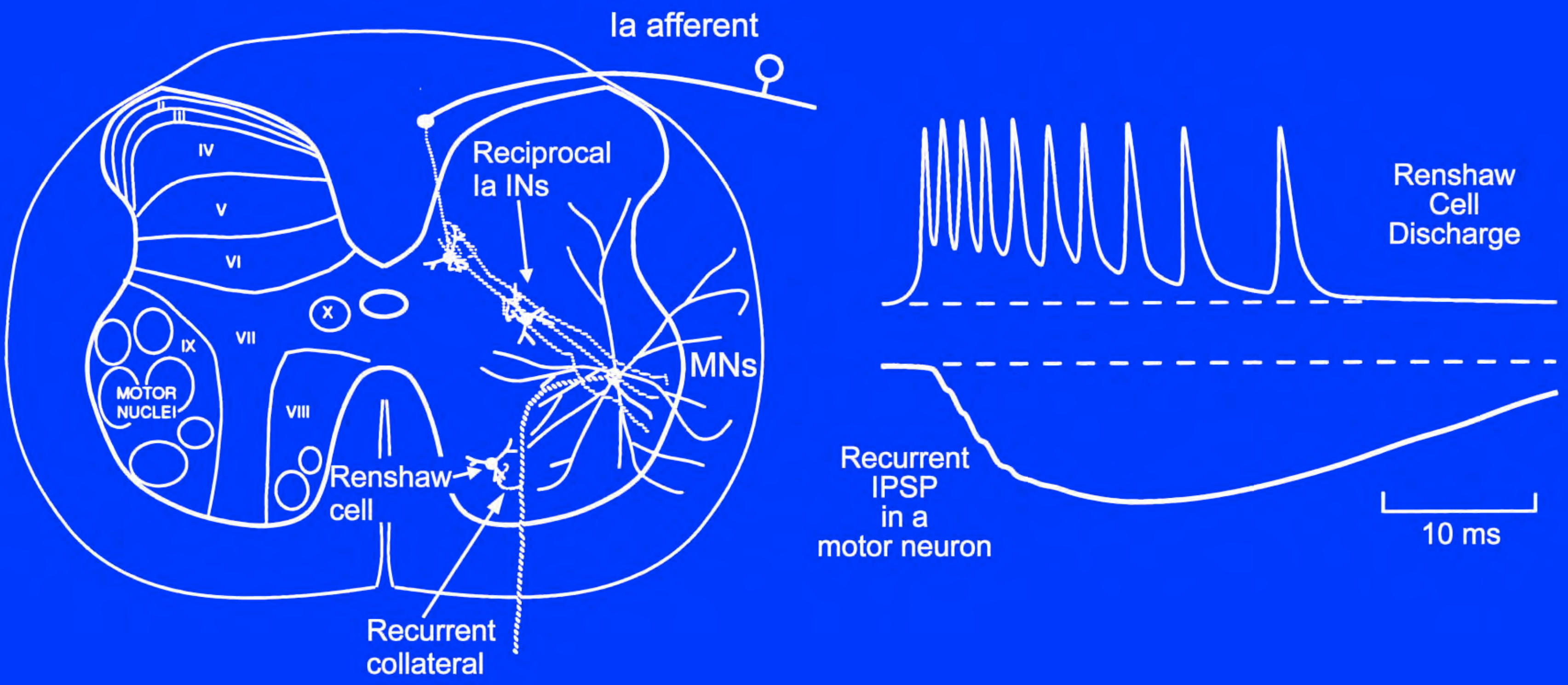
Renshaw 1946; J Neurophysiol; 9; 191-

RC responds to stimuli applied to two different nerves



Renshaw 1946

Renshaw cells



Renshaw cell termination patterns

1) Monosynaptic inhibition of motor neurons to homonymous and synergists, not antagonists. (similar to Ia distribution, but opposite in sign).

2) Inhibit reciprocal Ia interneurons to antagonists. (selection of synergists versus coactivation of muscles)

3) Mutual inhibition, strongest between cells receiving excitation from antagonists.

4) Strongest inhibition of S type motor neurons.

5) Widespread axonal arborization of 10-12 mm rostrocaudally

Input patterns from motor neuron collaterals

1) Synaptic input from FF type motor neurons > FR > S types. Possible selection of motor units not according to size principle.

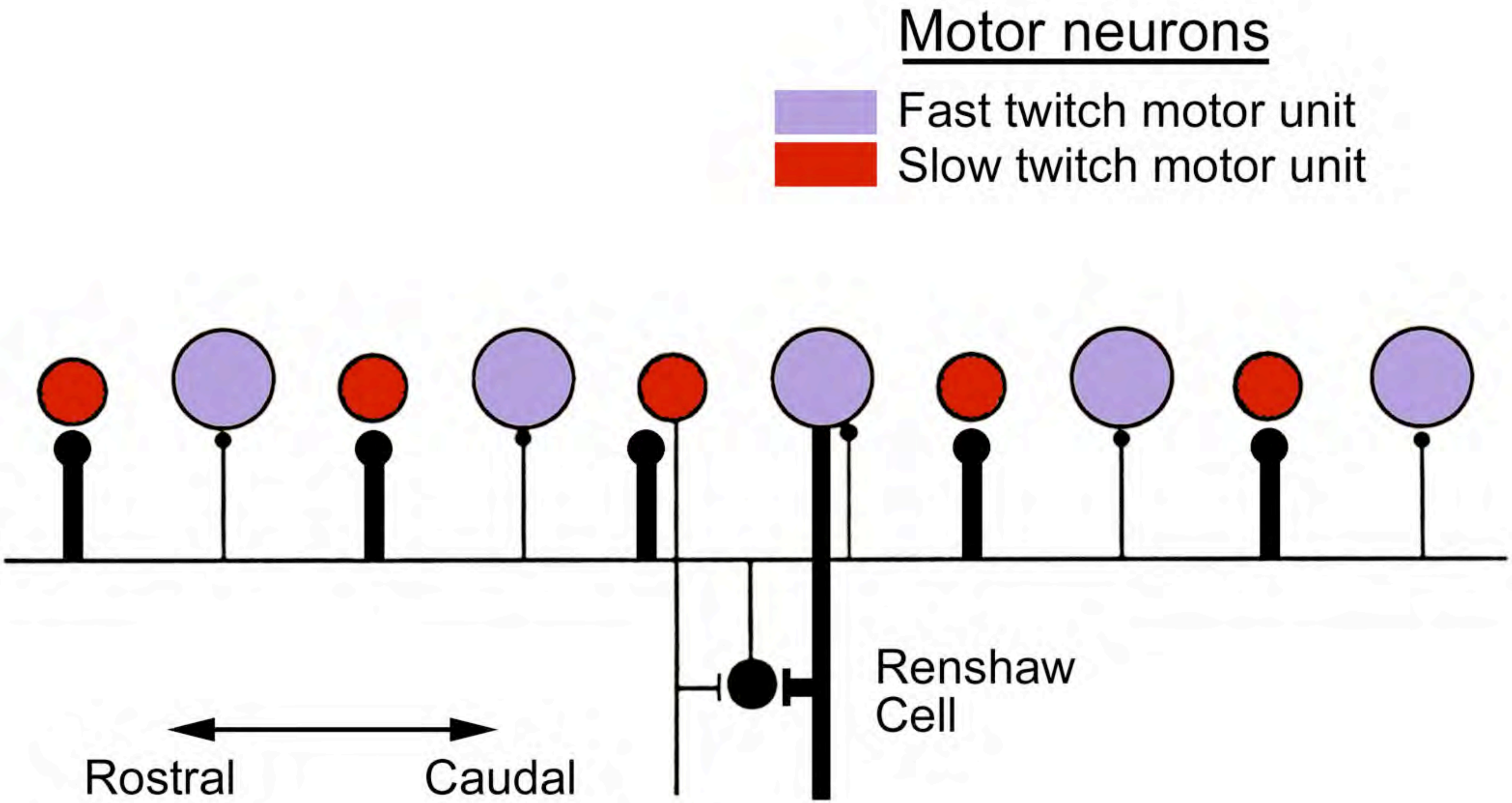
2) Greater input from proximal motor neurons than distal ones.

3) Localized input because of small dendritic tree (few hundred microns).

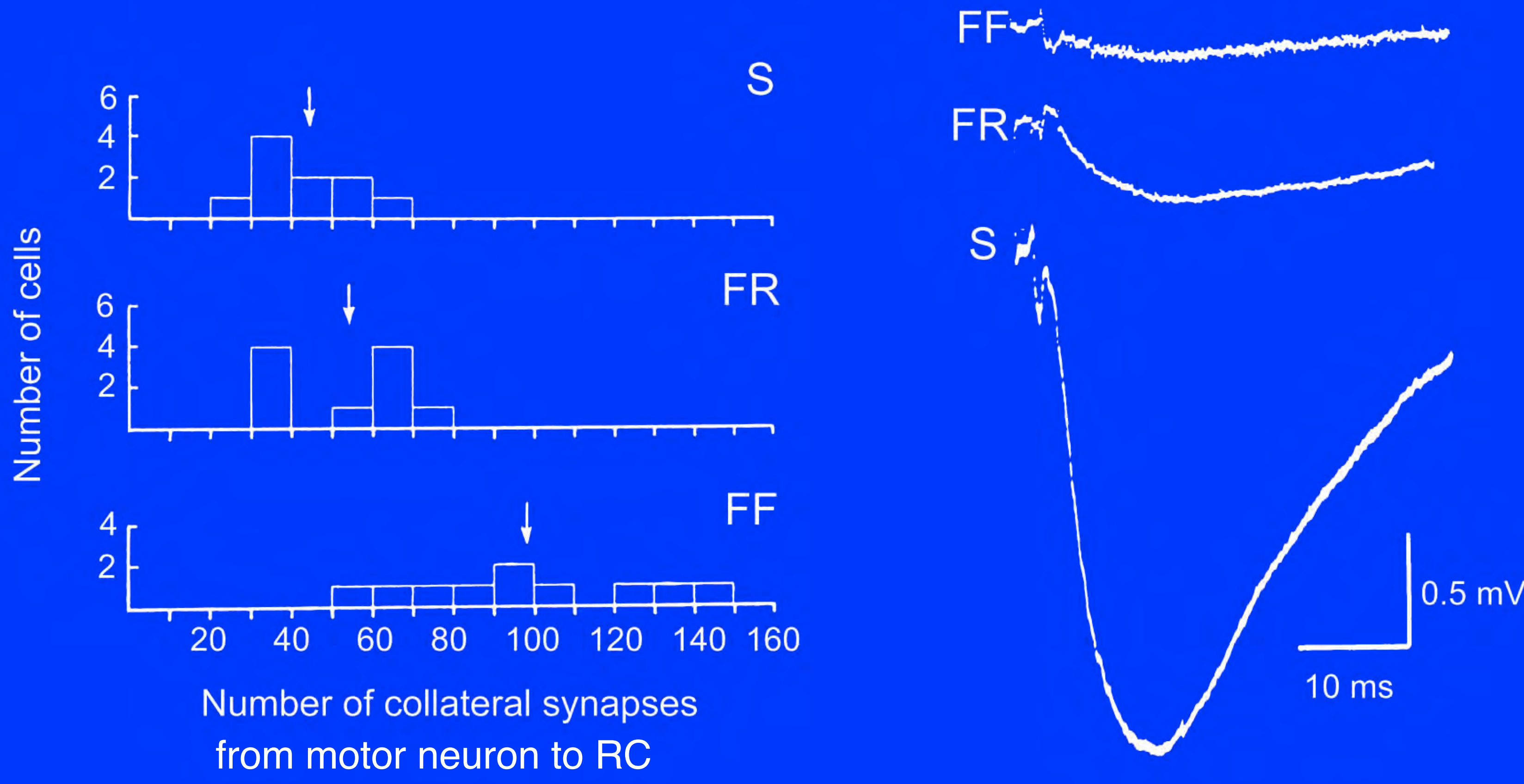
5 + 3---lateral inhibition effect

4 + 1---changing of recruitment order

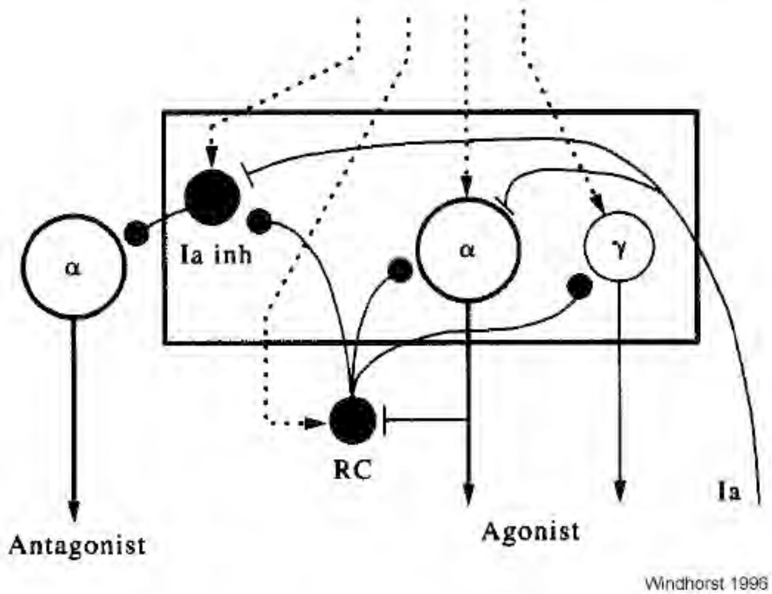
1 and 2 from top list ---possible role in locomotion

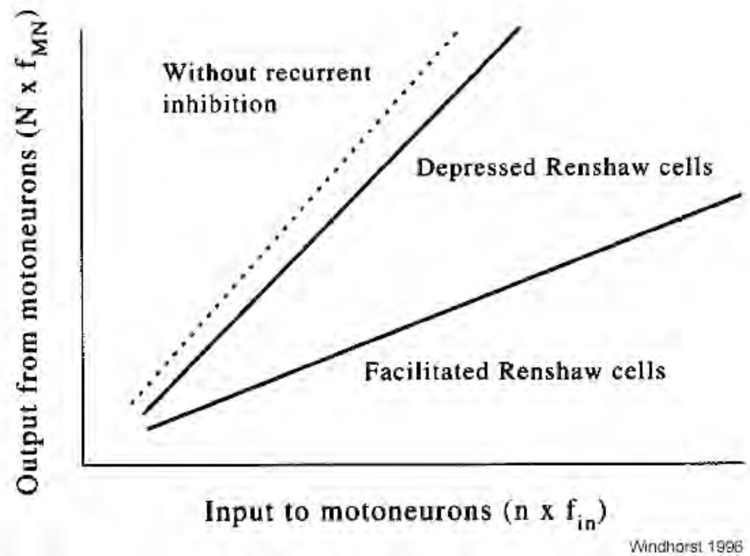

Motor neurons
Fast twitch motor unit
Slow twitch motor unit
Renshaw
Cell
Rostral
Caudal

Preferential inhibition of S motor units by Renshaw cells



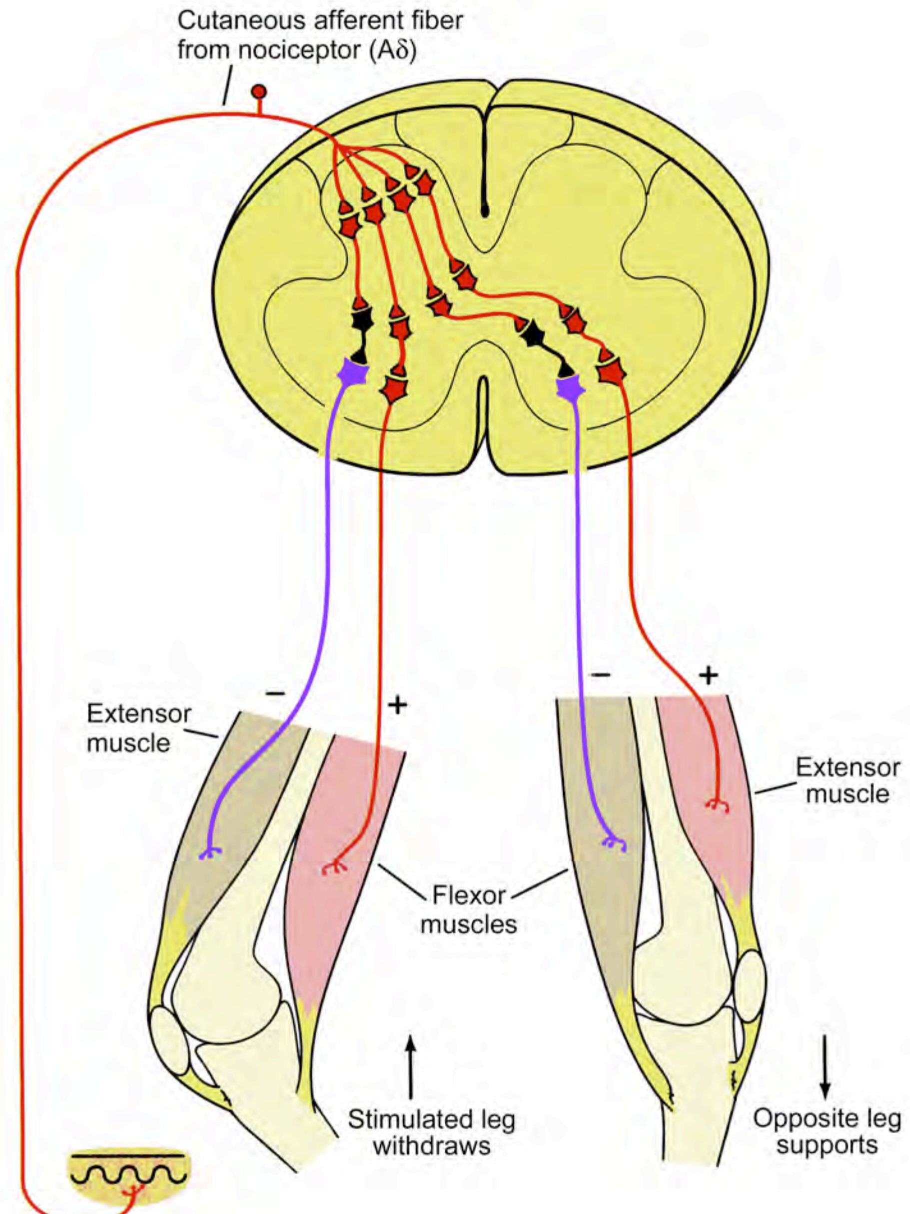
Negative feedback from RCs lowers and stabilizes motor neuron firing rates





- relation to proximal vs distal motor neuron function

FRA reflex circuit



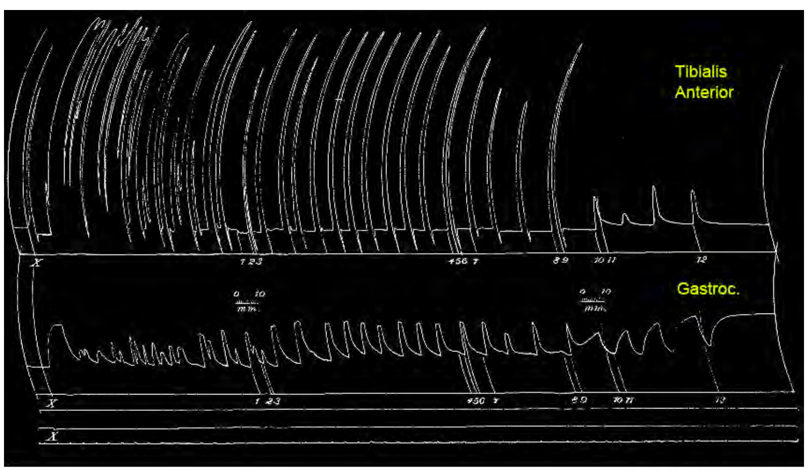
National Geographic

Locomotion early concepts

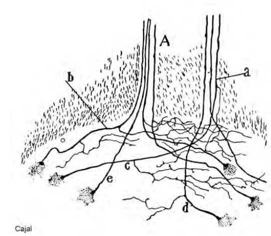
•Sherrington: Locomotion is automatic result of successive activation of reflexes. For example, alternating activation of Ia stretch reflex in flexors and extensors of limb, and FRA reflex with crossed extension component. Others suggested tactile initiated reflexes were important.

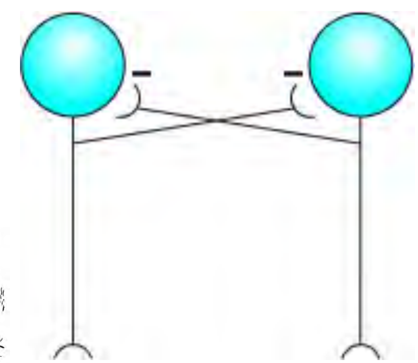
•Graham Brown: central rhythmogenesis by balanced antagonist half centers—it is the interaction of the two centers that generates the rhythm.

Locomotion in deafferented cat



Graham Brown (1911)





CPG (central pattern generator)

A set of neurons and circuits capable of generating rhythmic activity that underlies motor acts, even in the absence of sensory input.

Renshaw cells and Ia ITNs may form CPG for controlling flexor and extensor contractions during locomotion

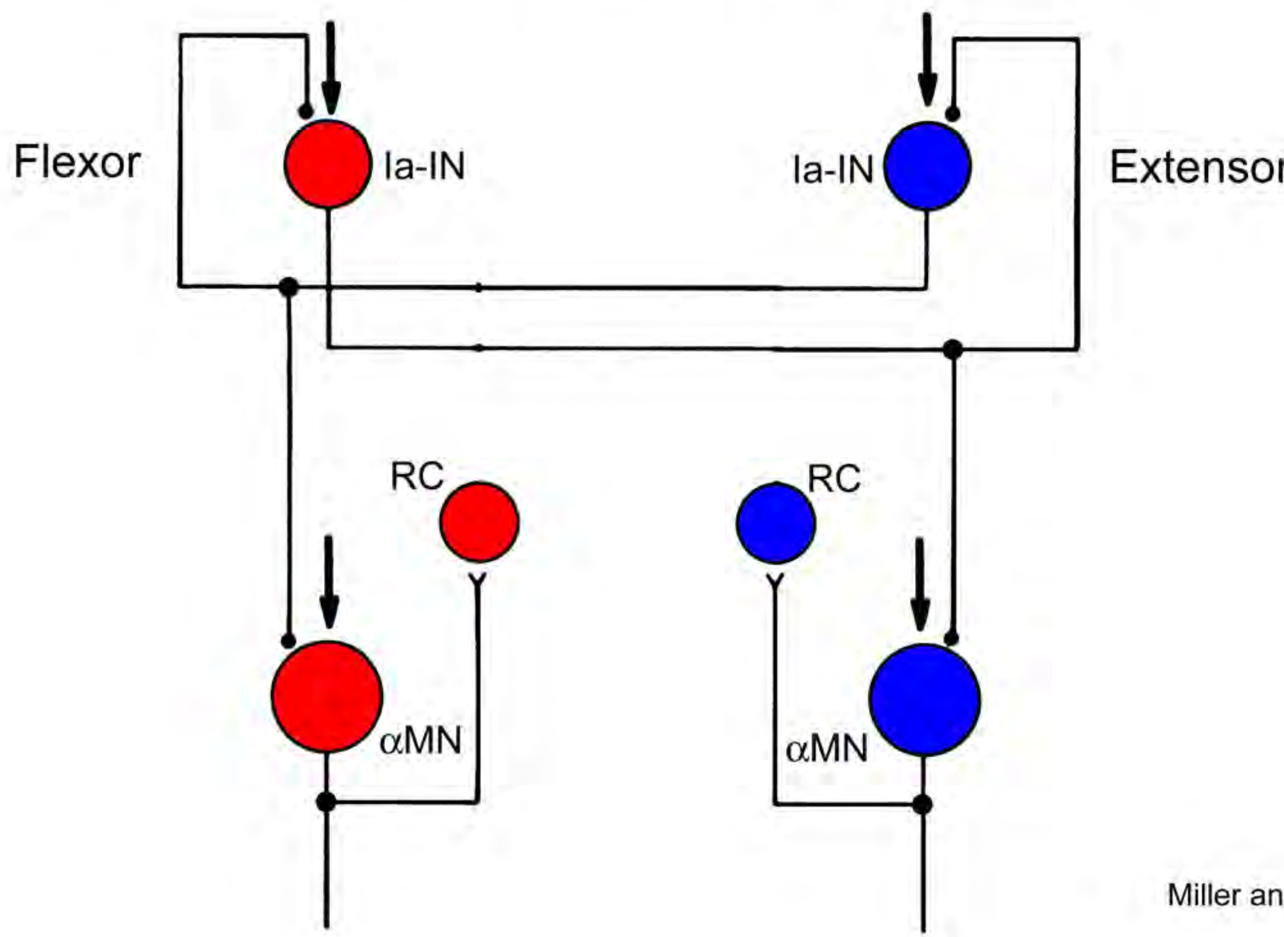
Renshaw cell termination patterns

1) Monosynaptic inhibition of motor neurons to homonymous and synergists, not antagonists.
   (similar to Ia distribution, but opposite in sign).

2) Inhibit reciprocal Ia interneurons to antagonists.
   (selection of synergists versus coactivation of muscles)

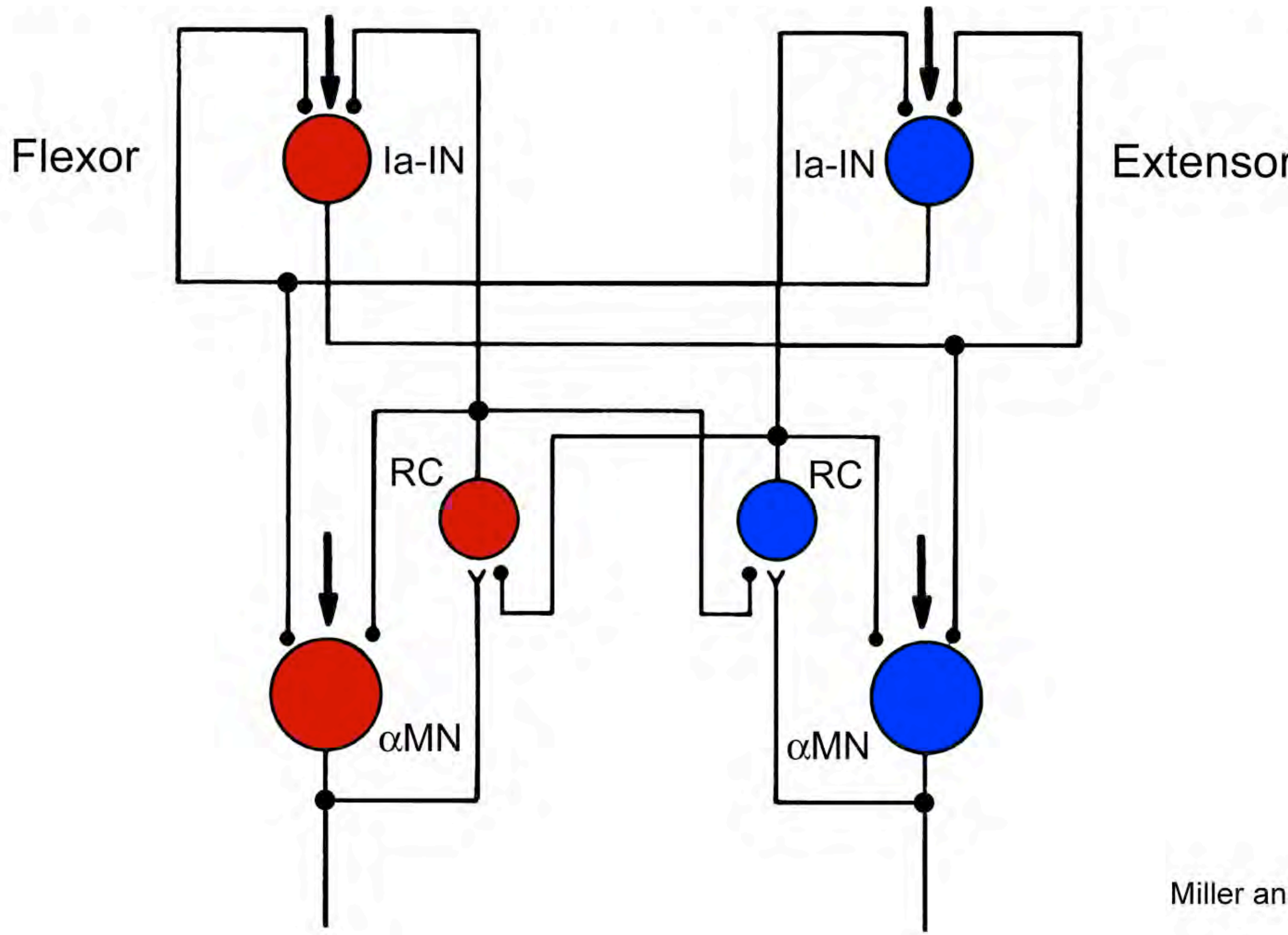
3) Mutual inhibition, strongest between cells receiving excitation from antagonists.

First consider just the reciprocal Ia Itns and Mtns



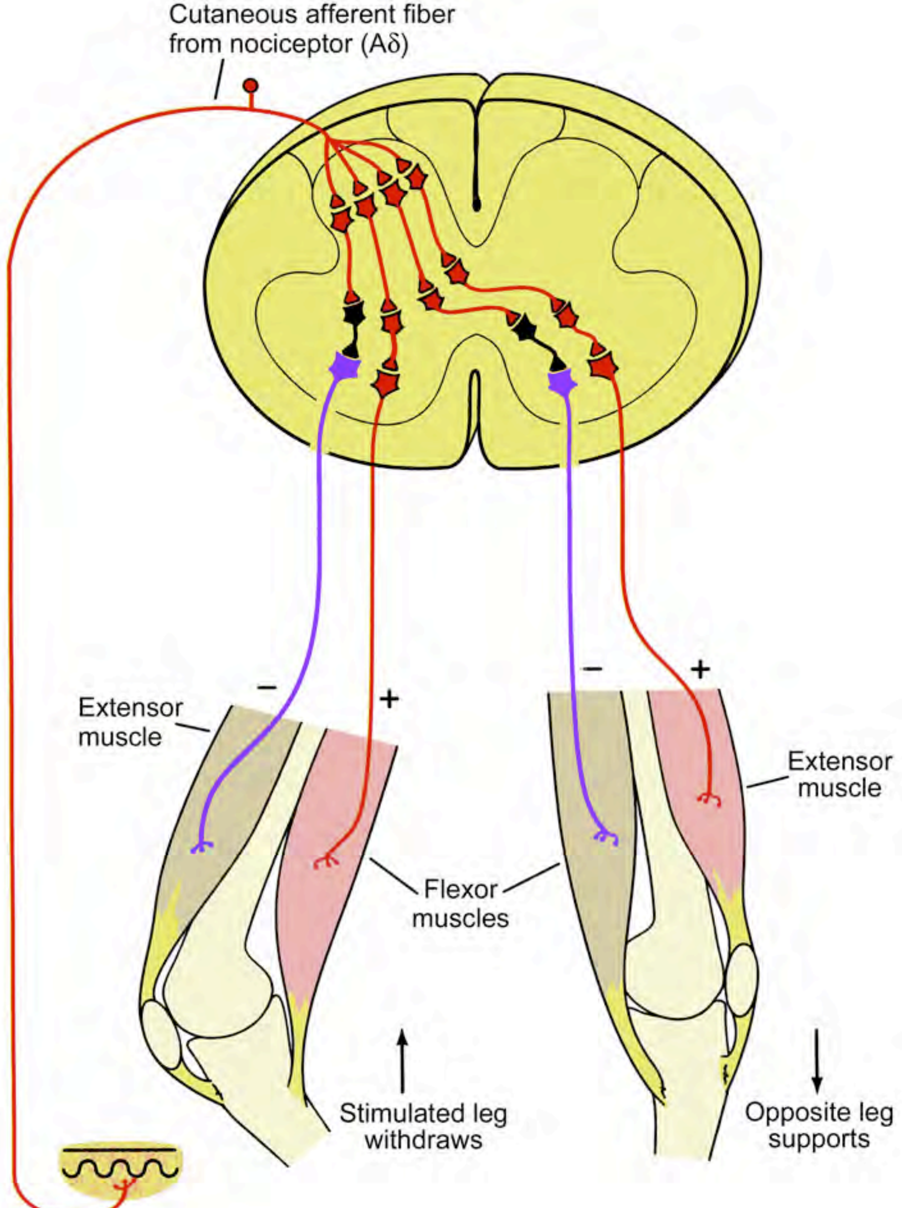
Miller and Scott, 1980

now add in the RCs to get a circuit that could generate rhythmic activity

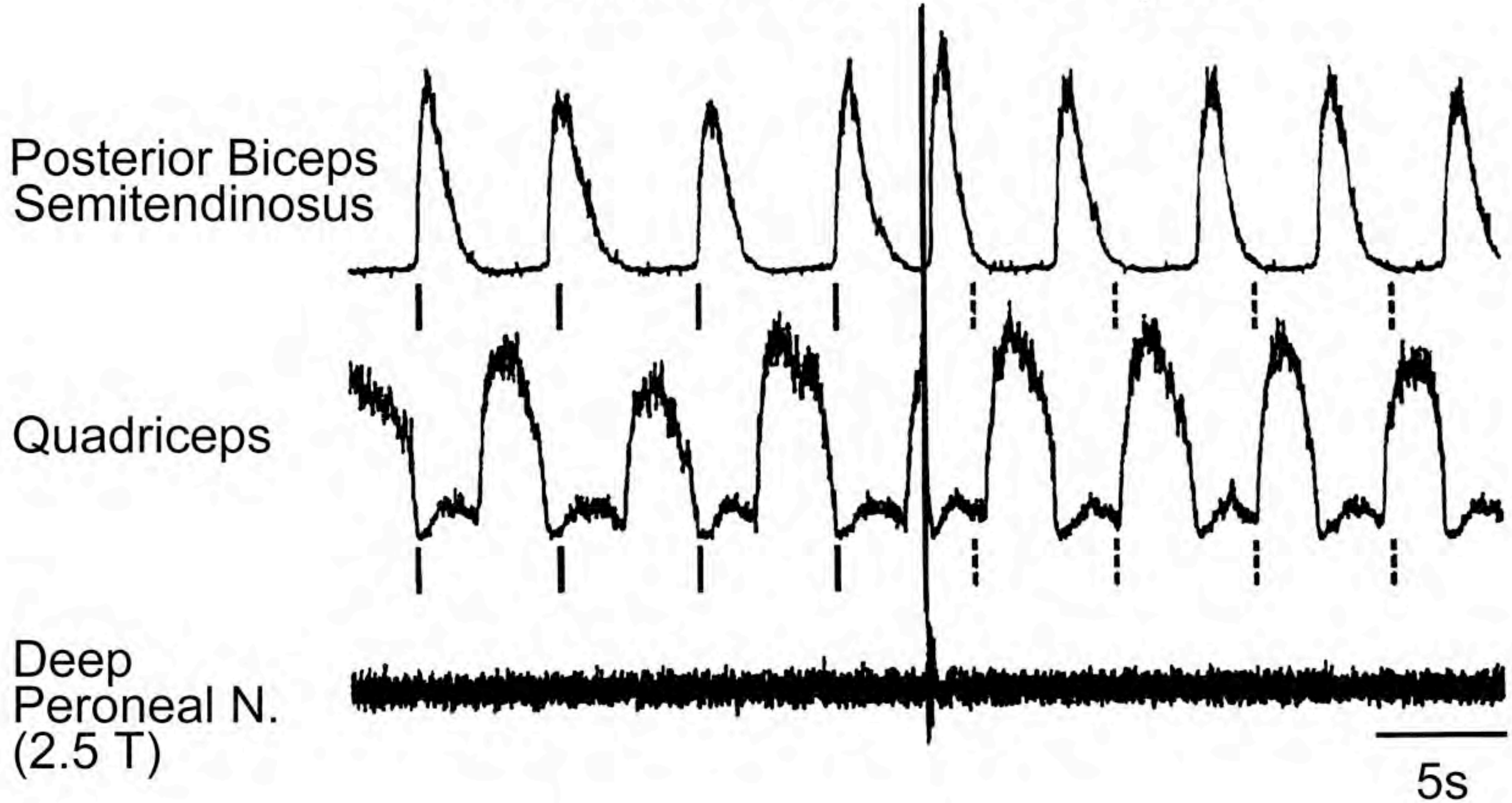


Miller and Scott, 1980

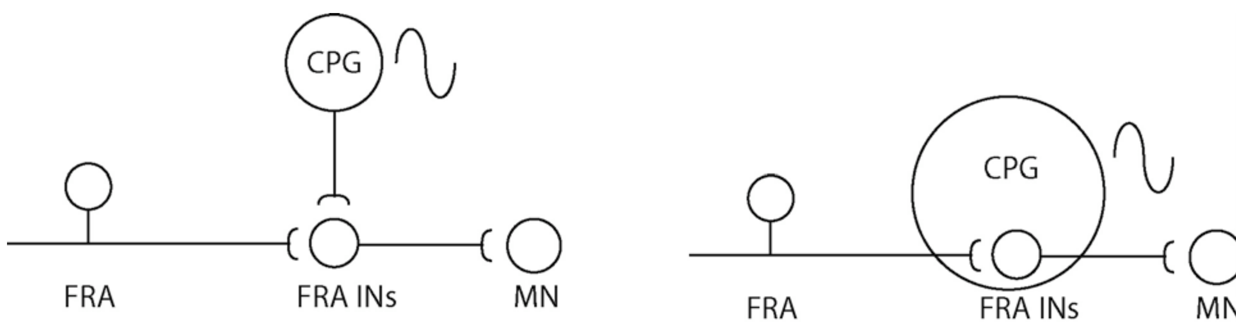
FRA reflex circuit



FRA stimulus resets CPG cycle



Hultborn et al., 1998

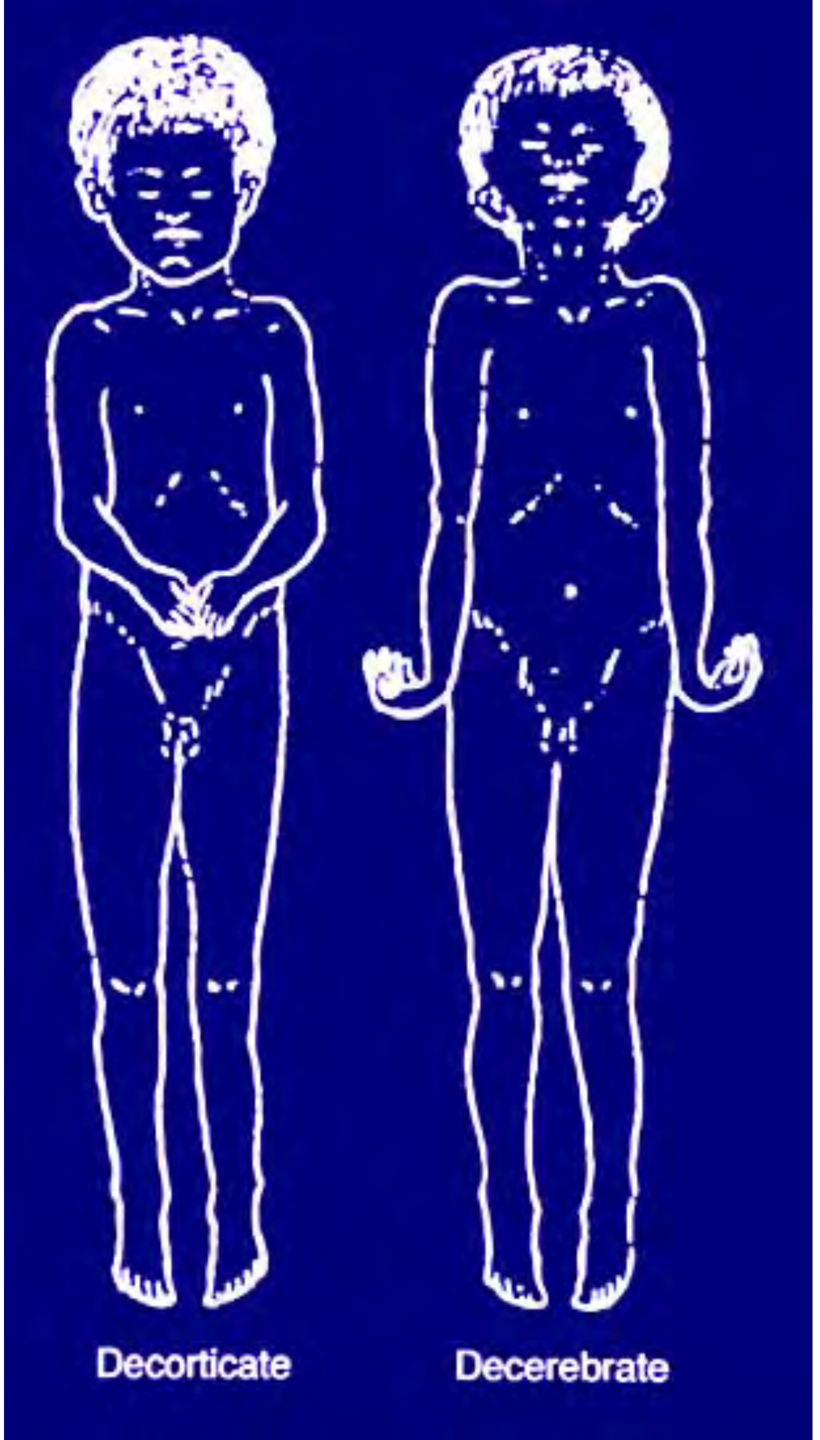


Descending Motor Pathways and their role in muscle tone

'upper motor neurons'

1. Corticospinal
2. Rubrospinal
3. Pontine Reticulospinal (medial)
4. Medullary Reticulospinal (lateral)
5. Lateral Vestibulospinal

Decerebrate and decorticate postures



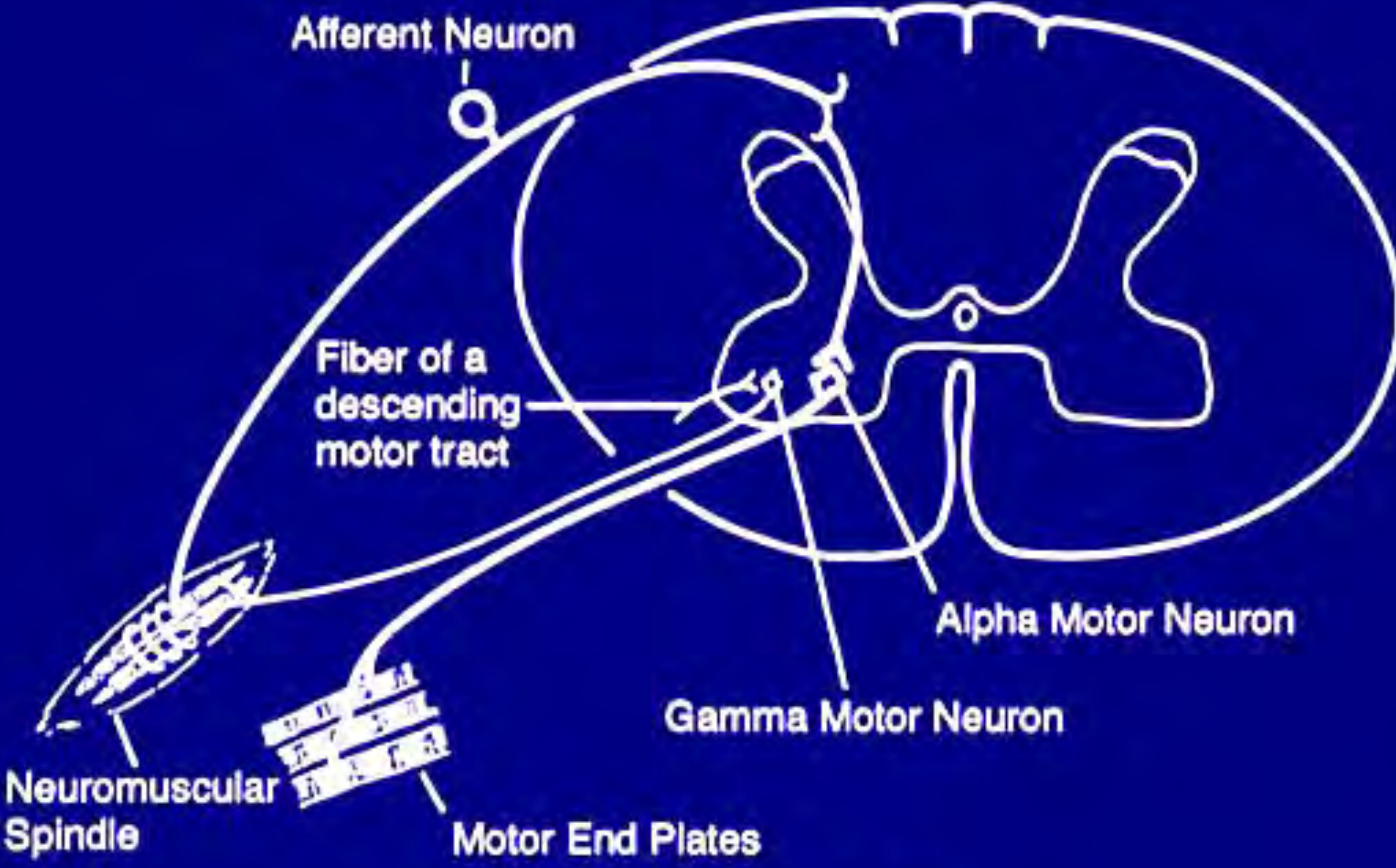
Decerebrate Rigidity

Lesion Sites

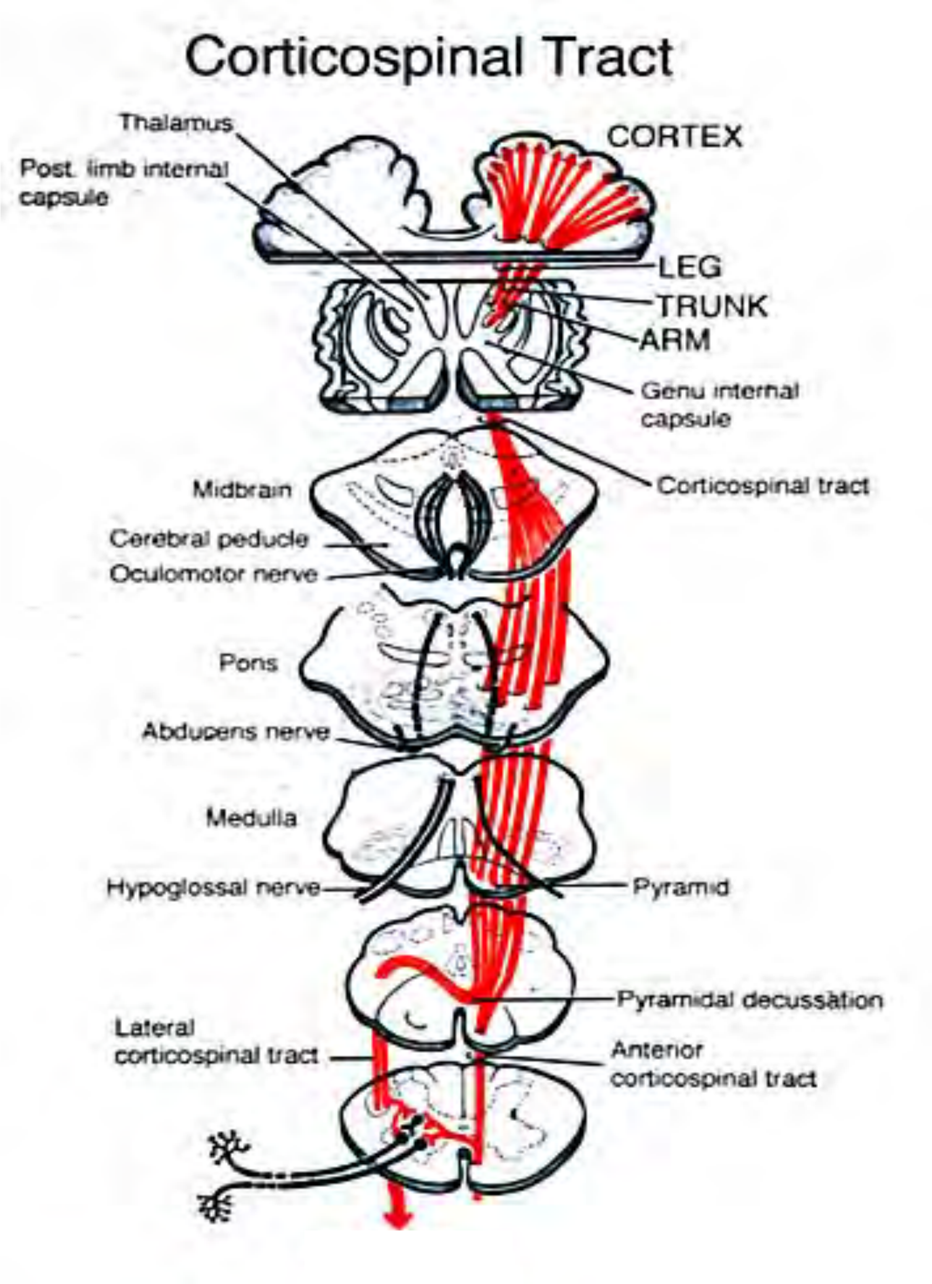
1. Midbrain lesions (cerveau isolé)
2. Anterior vermis of the cerebellar cortex

Mechanisms

1. Alpha rigidity
2. Gamma rigidity

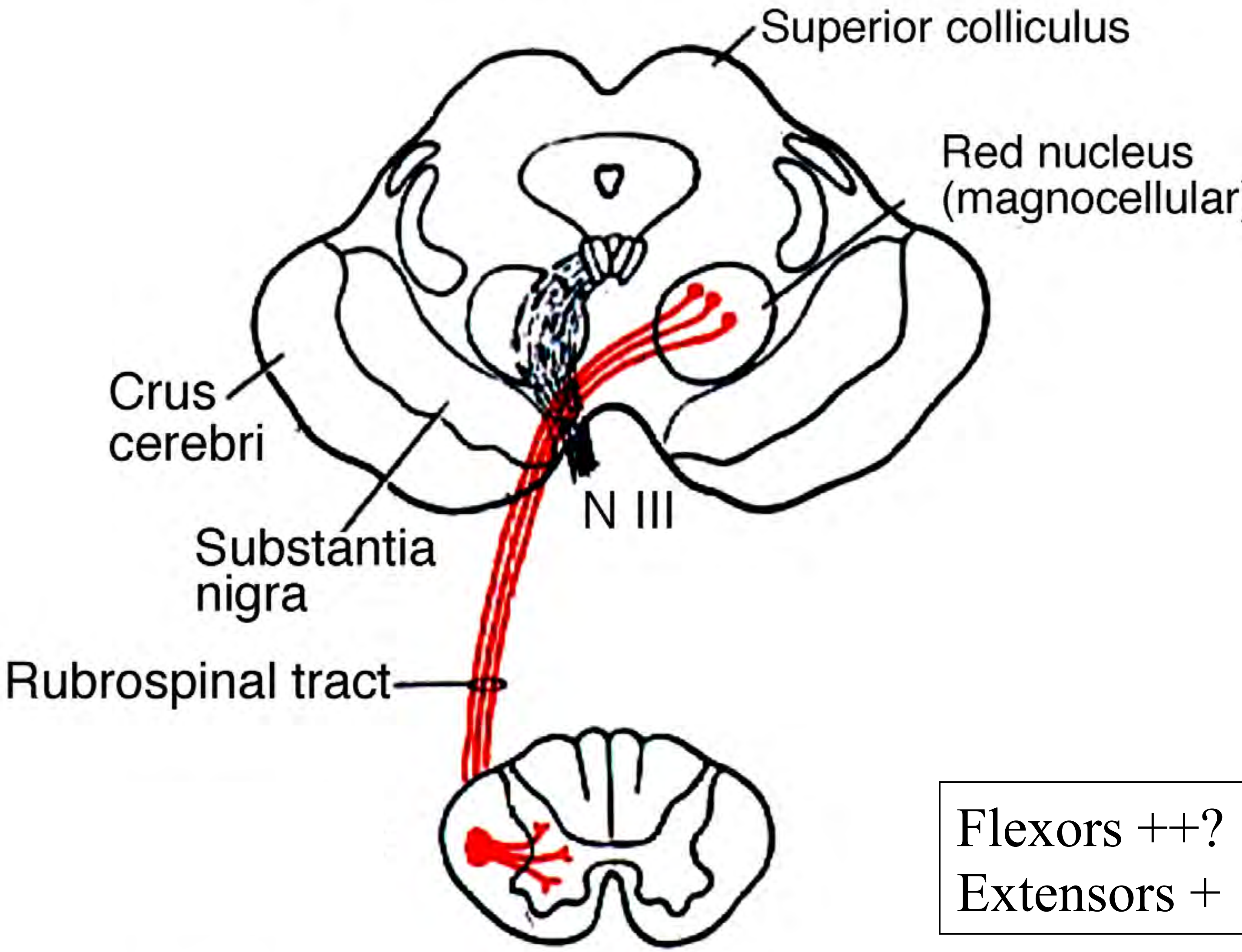


Gamma Reflex Loop



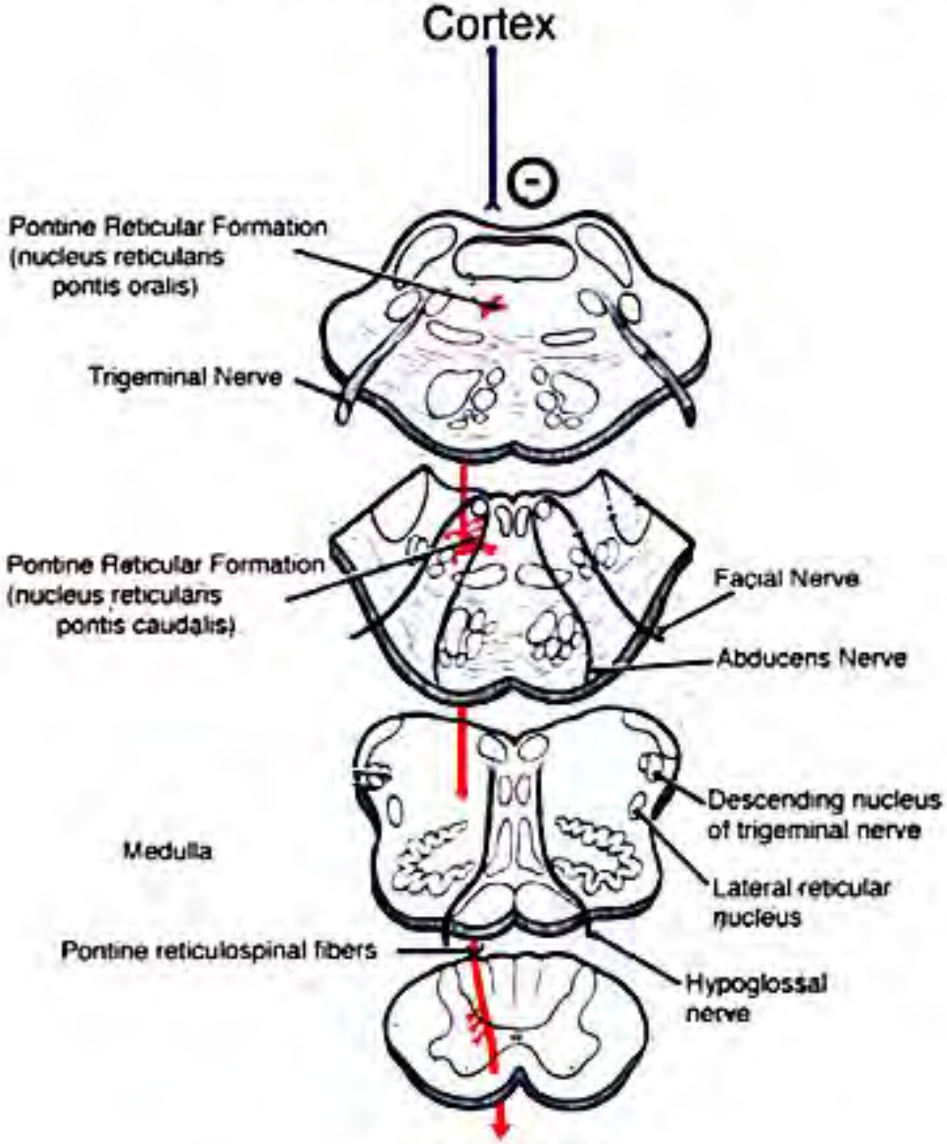
Flexors ++
Extensors +

Rubrospinal Tract



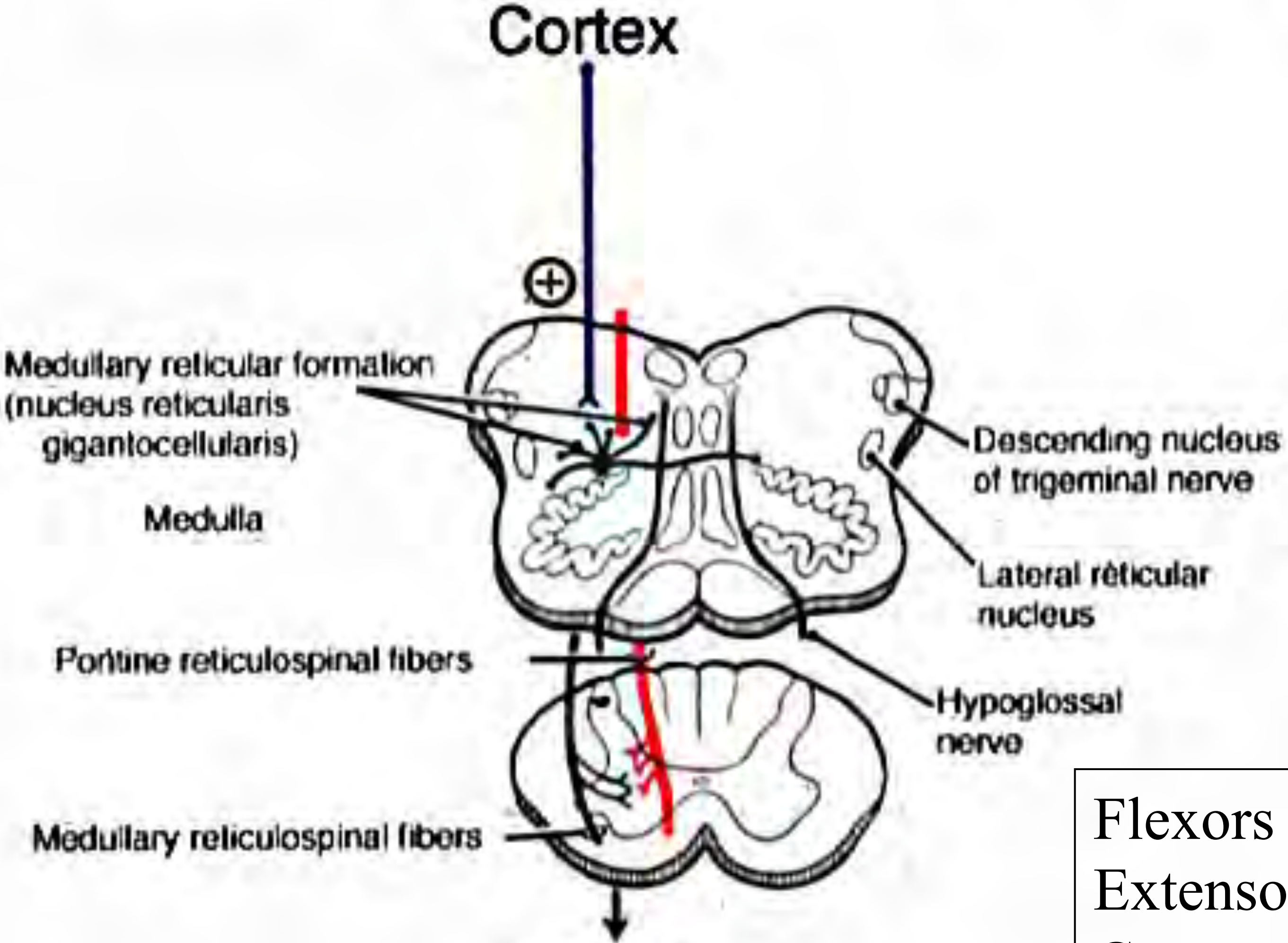
Flexors ++?
Extensors +

Pontine Reticulospinal Pathway



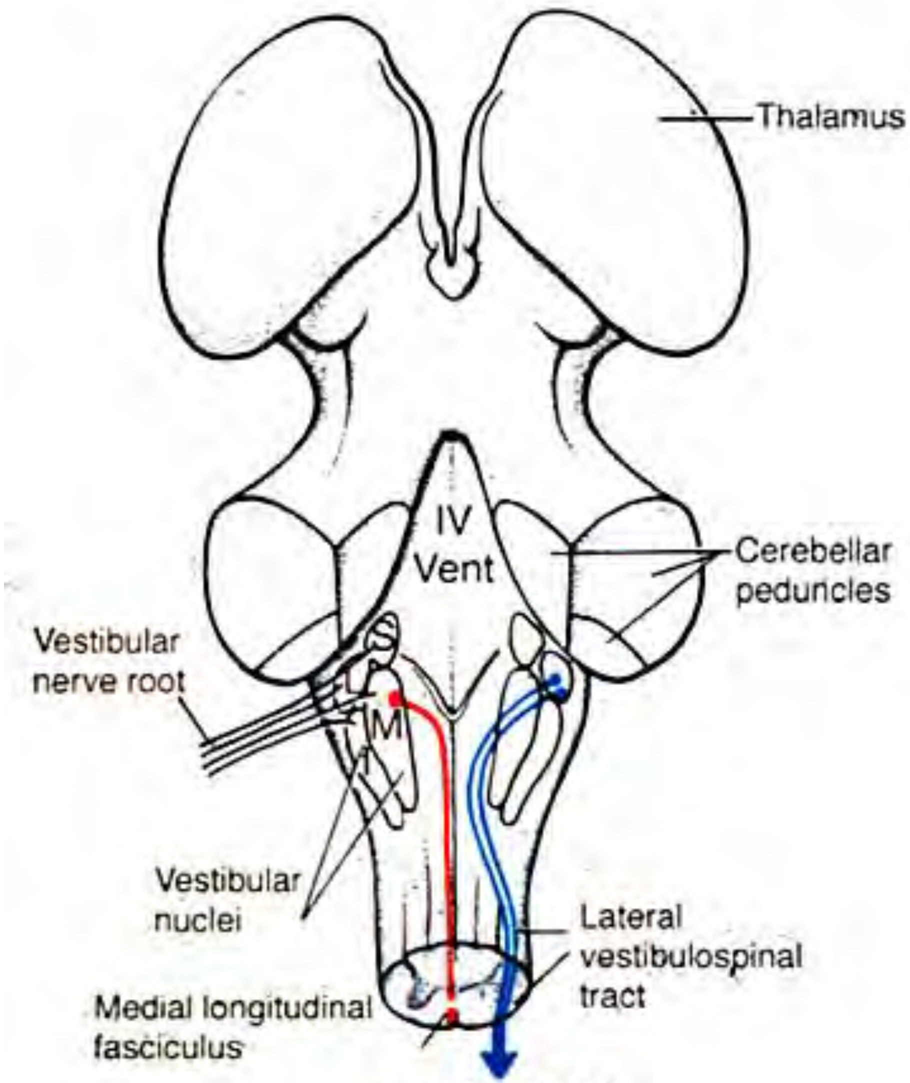
Flexors +
Extensors ++
Gamma>Alpha

Medullary Reticulospinal Pathway

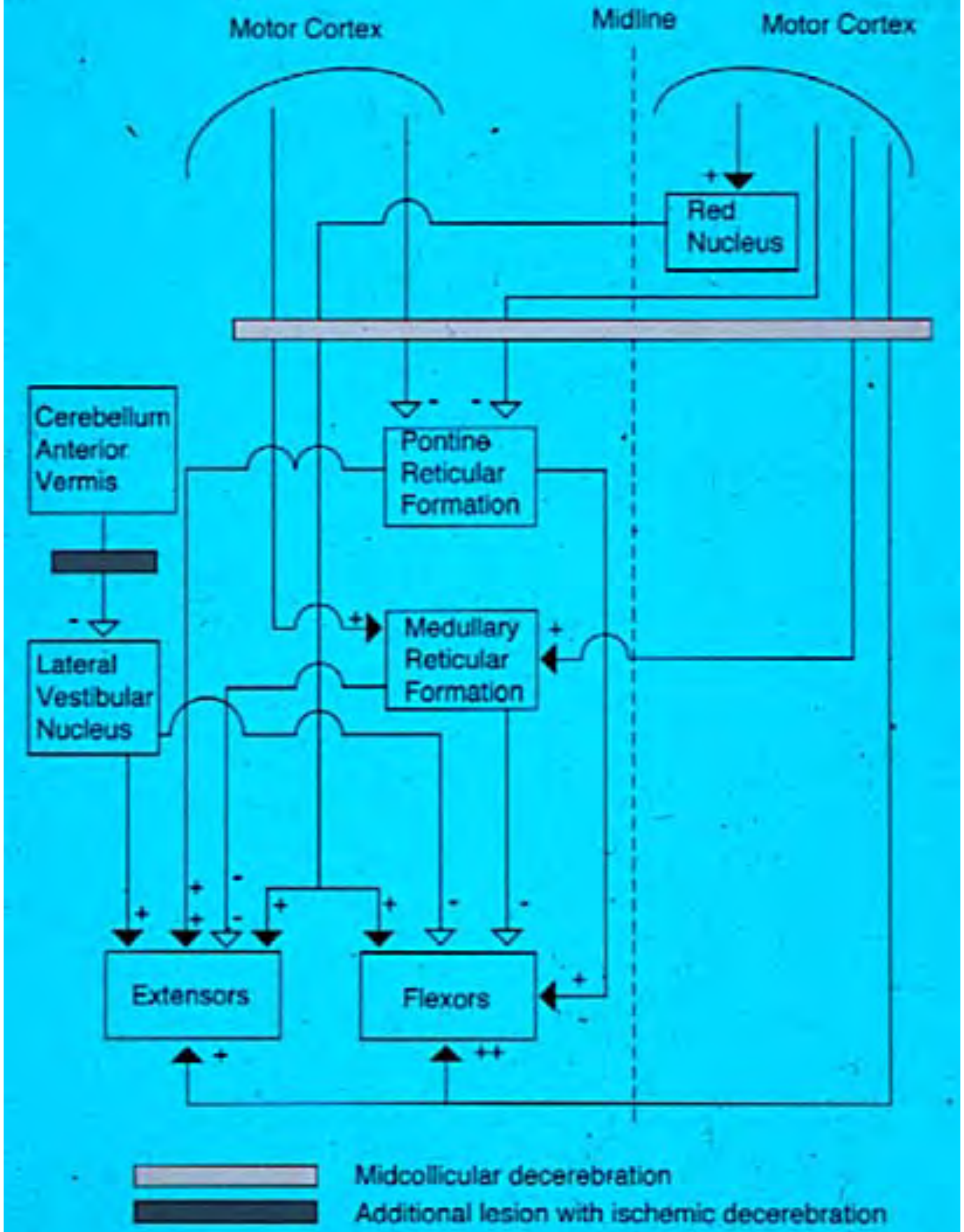


Flexors -
Extensors --
Gamma>Alpha

Lateral Vestibulospinal Tract



Flexors -
Extensors +
Alpha motor neurons



Motor Cortex
Midline
Motor Cortex
Red Nucleus
Cerebellum Anterior Vermis
Pontine Reticular Formation
Medullary Reticular Formation
Lateral Vestibular Nucleus
Extensors
Flexors
Midcollicular decerebration
Additional lesion with ischemic decerebration