Motor Systems: Motor Units and Spinal Cord Circuitry, Spinal Anatomy, Reflexes and Central Pattern Generators

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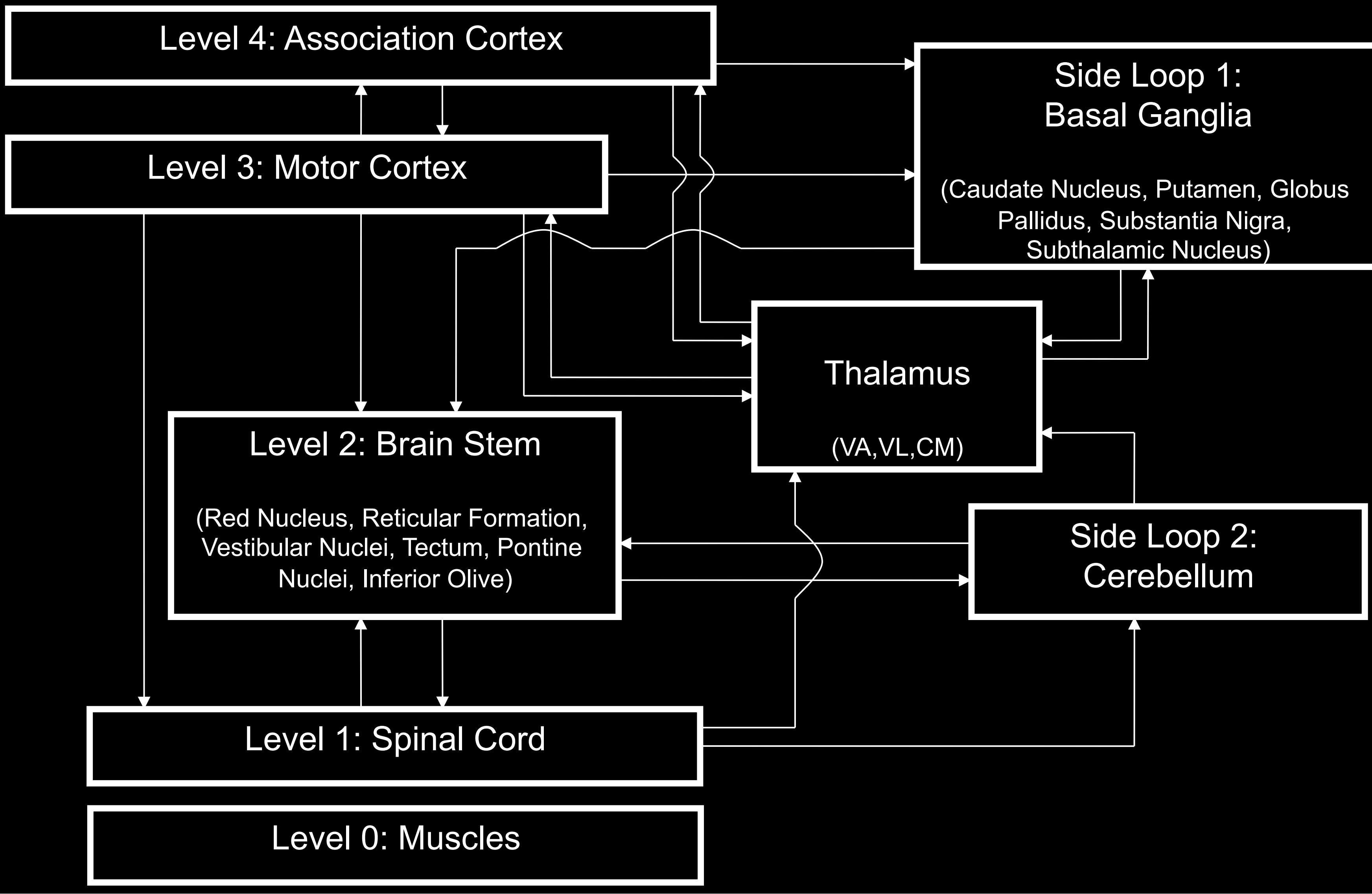
Hierarchical Organization and Functional Segregation of Central Motor Structures



Preamble

How well do we understand the brain?

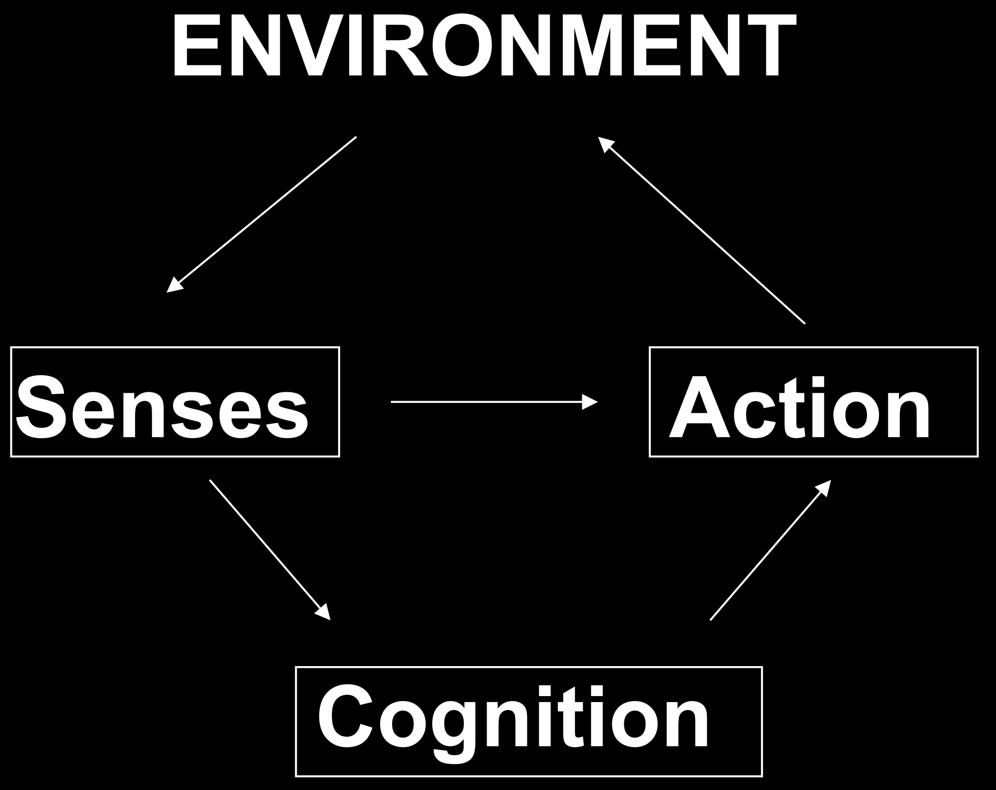
A. 0.1%
B. 1%
C. 10%
D. 90%

How much of what medical students learn is wrong or irrelevant?

A. 0.1%
B. 1%
C. 10%
D. 90%

Motor control, how does it work?

MOTOR CONTROL



Necessary Components of Proper Motor Control

- Volition
-

Necessary Components of Proper Motor Control

- Volition
- Coordination of signals to many muscle groups
-

Necessary Components of Proper Motor Control

- Volition
- Coordination of signals to many muscle groups
- Proprioception
-

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- Postural adjustments
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- Sensory feedback
- Compensation for body and muscles
- Unconscious processing
-

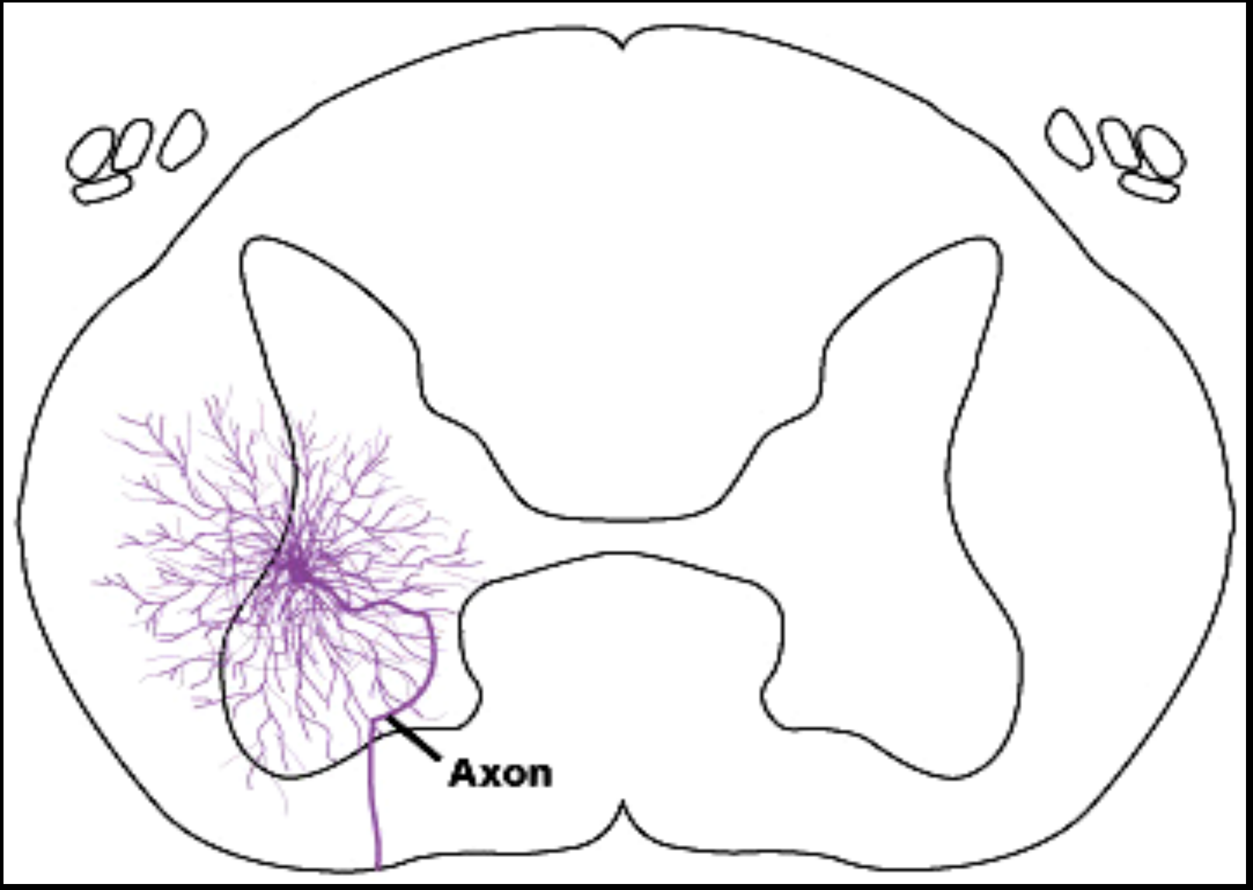
Necessary Components of Proper Motor Control

- Volition
- Coordination of signals to many muscle groups
- Proprioception
- Postural adjustments
- Sensory feedback
- Compensation for body and muscles
- Unconscious processing
- Adaptability

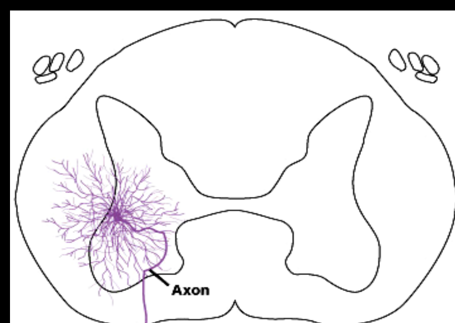
Spinal Cord

- Reflexes
- Rhythmic Movements
- **Motor control of body**

Alpha motor neuron (lower motor neuron)



Motor neurons + muscle



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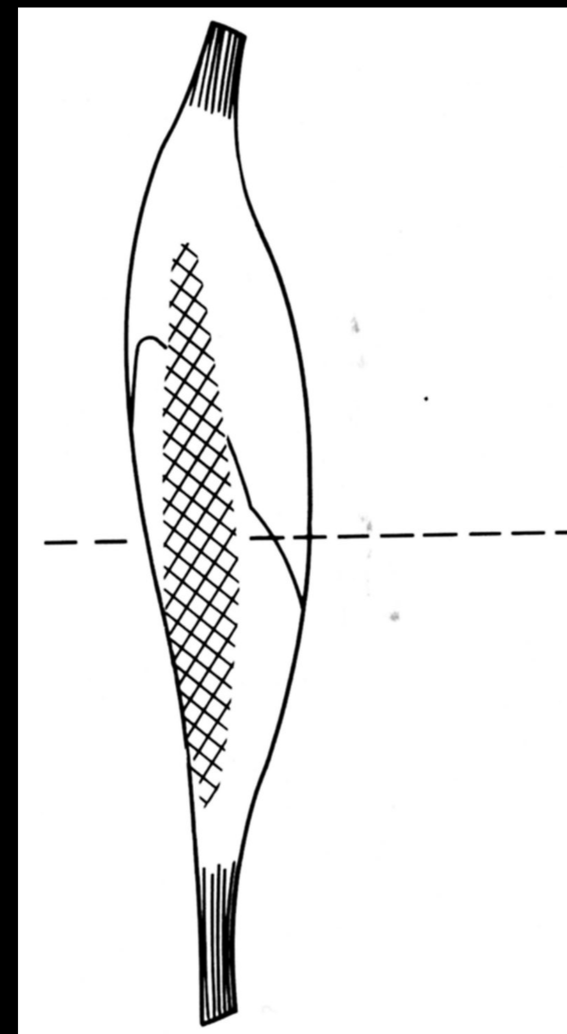


Diseases

Neurogenic

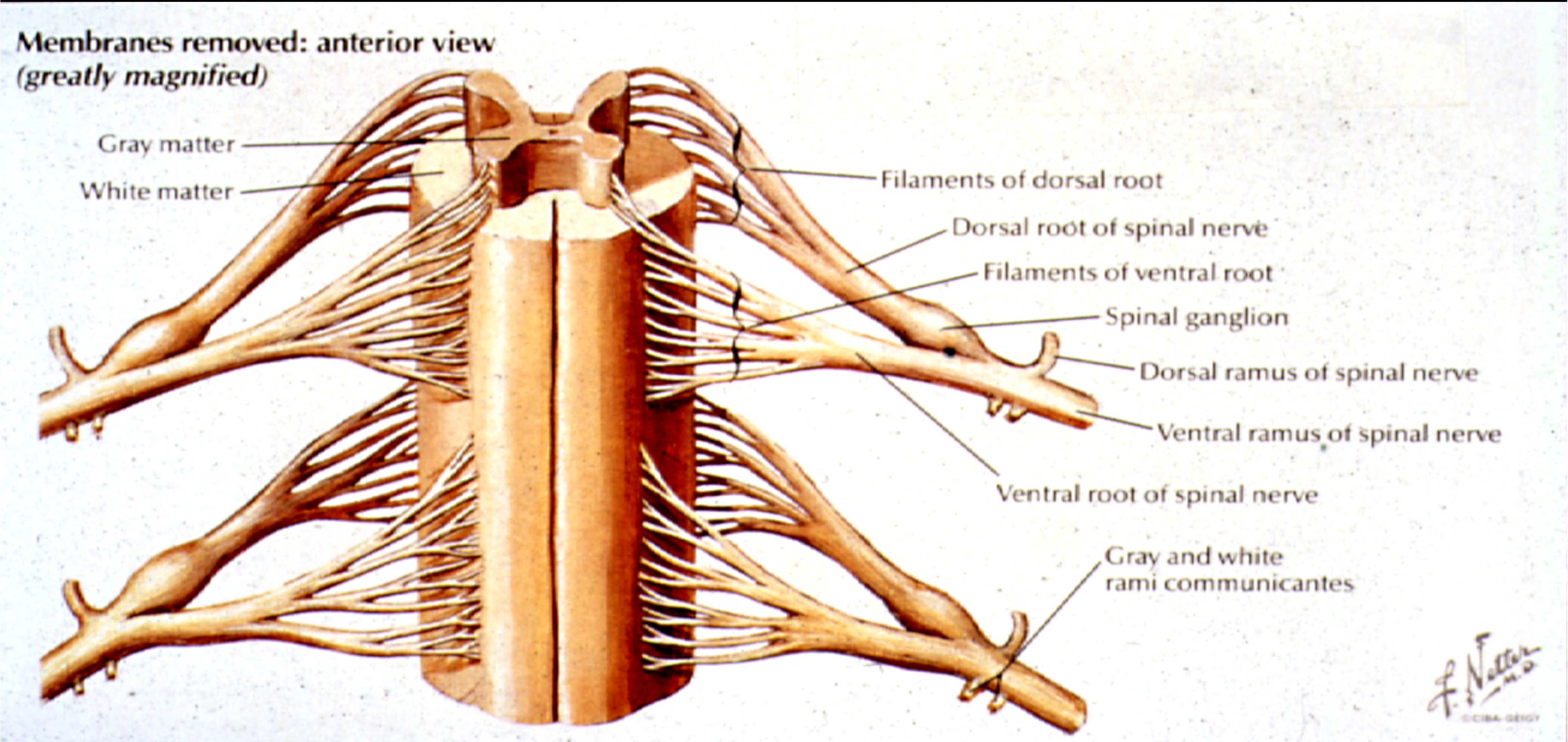
etiology: damage to lower motor neurons

e.g. ALS, Polio, Neuropathies, Guillan-Barre

Myopathic

etiology: degeneration of muscles

e.g. Muscular dystrophy, polymyositis


Membranes removed: anterior view
(greatly magnified)
Gray matter
White matter
Filaments of dorsal root
Dorsal root of spinal nerve
Filaments of ventral root
Spinal ganglion
Dorsal ramus of spinal nerve
Ventral ramus of spinal nerve
Ventral root of spinal nerve
Gray and white
rami communicantes
F. Netter M.D.
©CIBA-GEIGY

Motor control requires sensory input

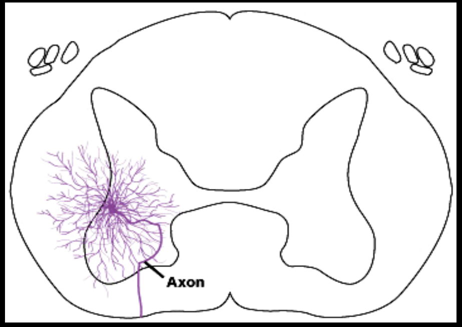
The case of Ian Waterman

- **Lost all somatosensory and proprioceptive input**
- **Initially unable to make any coordinated movement**
- **After years of practice he trained himself to make movement under visual guidance**
- **Requires total concentration to move and even maintain posture**
- **Collapses to ground when lights unexpectedly go out**

Jonathan Cole, *Pride and a Daily Marathon,* MIT Press, 1995.


BBC PRIME

Motor Unit



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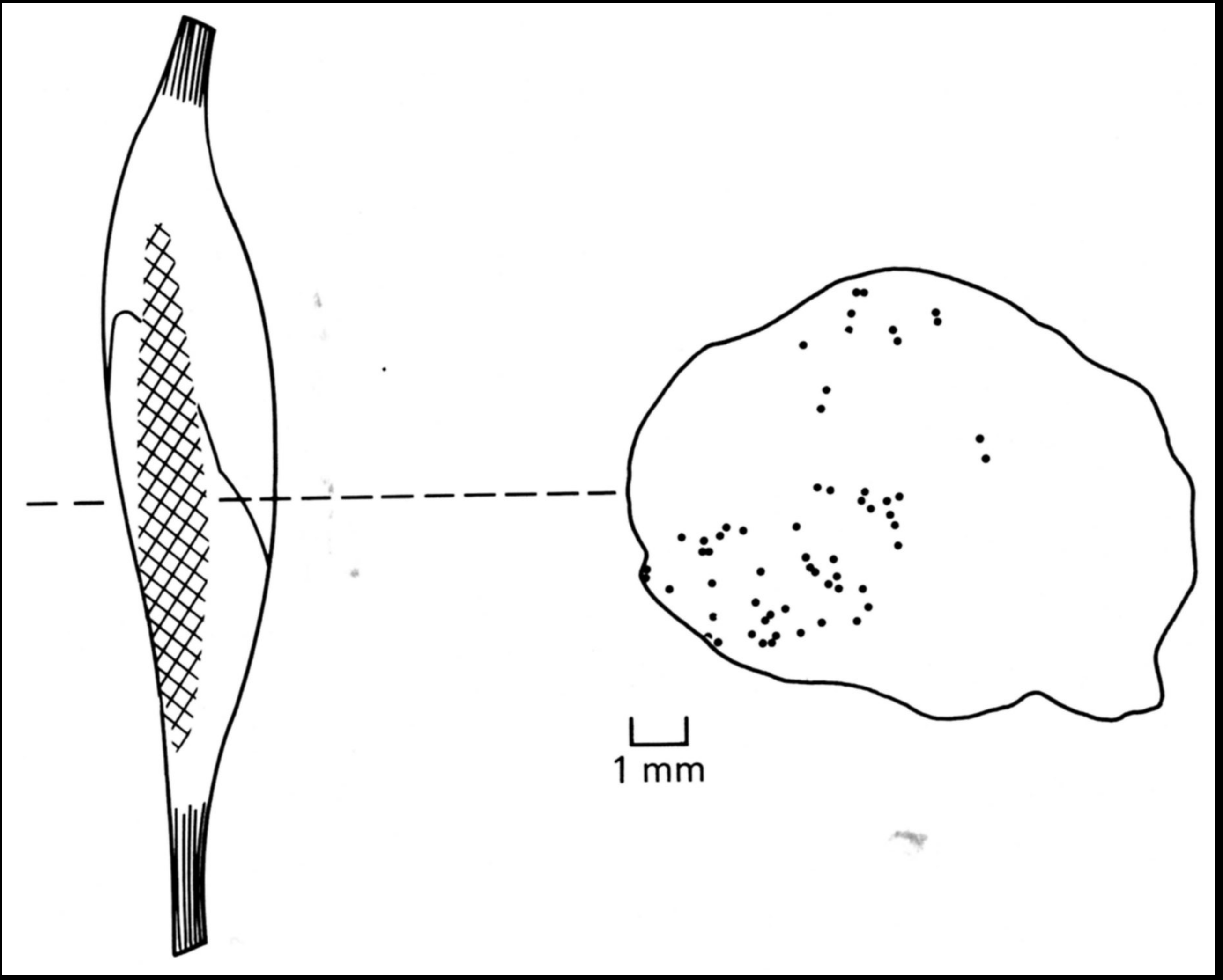


Motor Neuron Pool (Motor Nucleus)

The group of motor neurons that innervate an individual muscle

Motor Neuron Pool

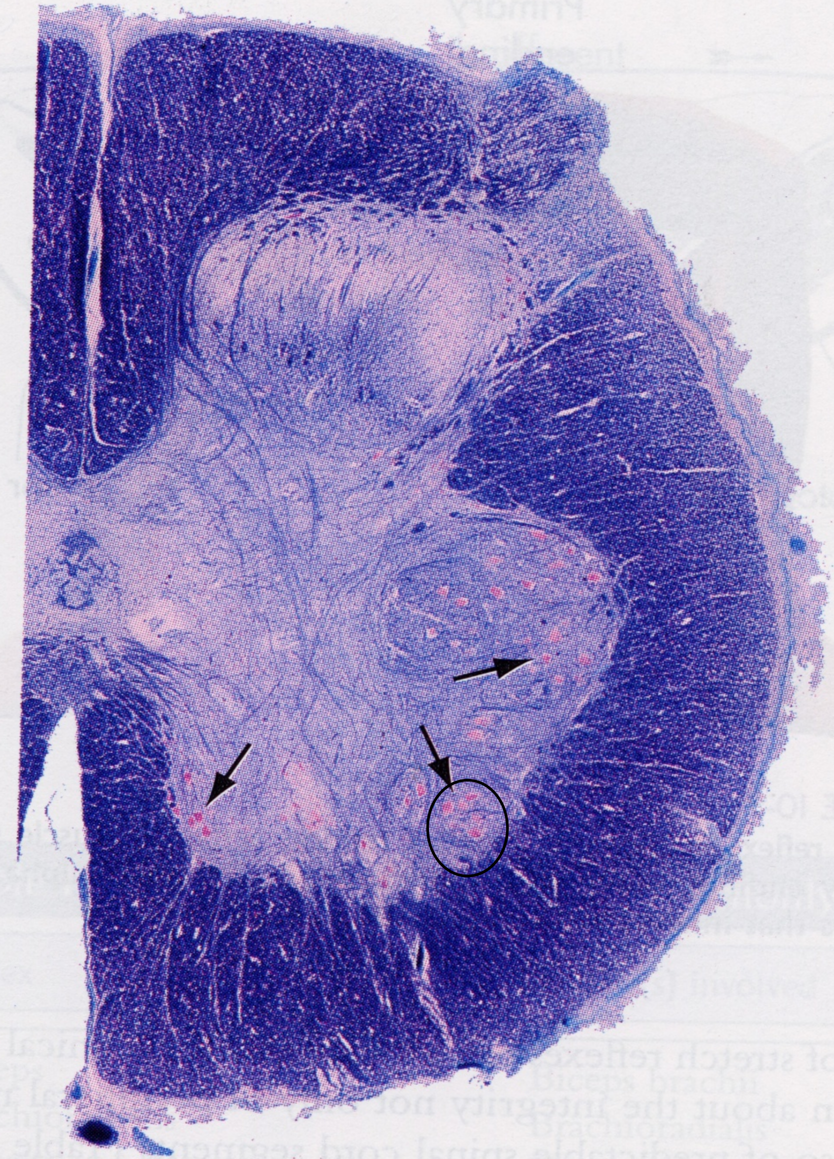


FIGURE 10-8
Clusters of motor neurons in the anterior horn at S4.

From J. Nolte (2002) *The Human Brain, 5th Edition*

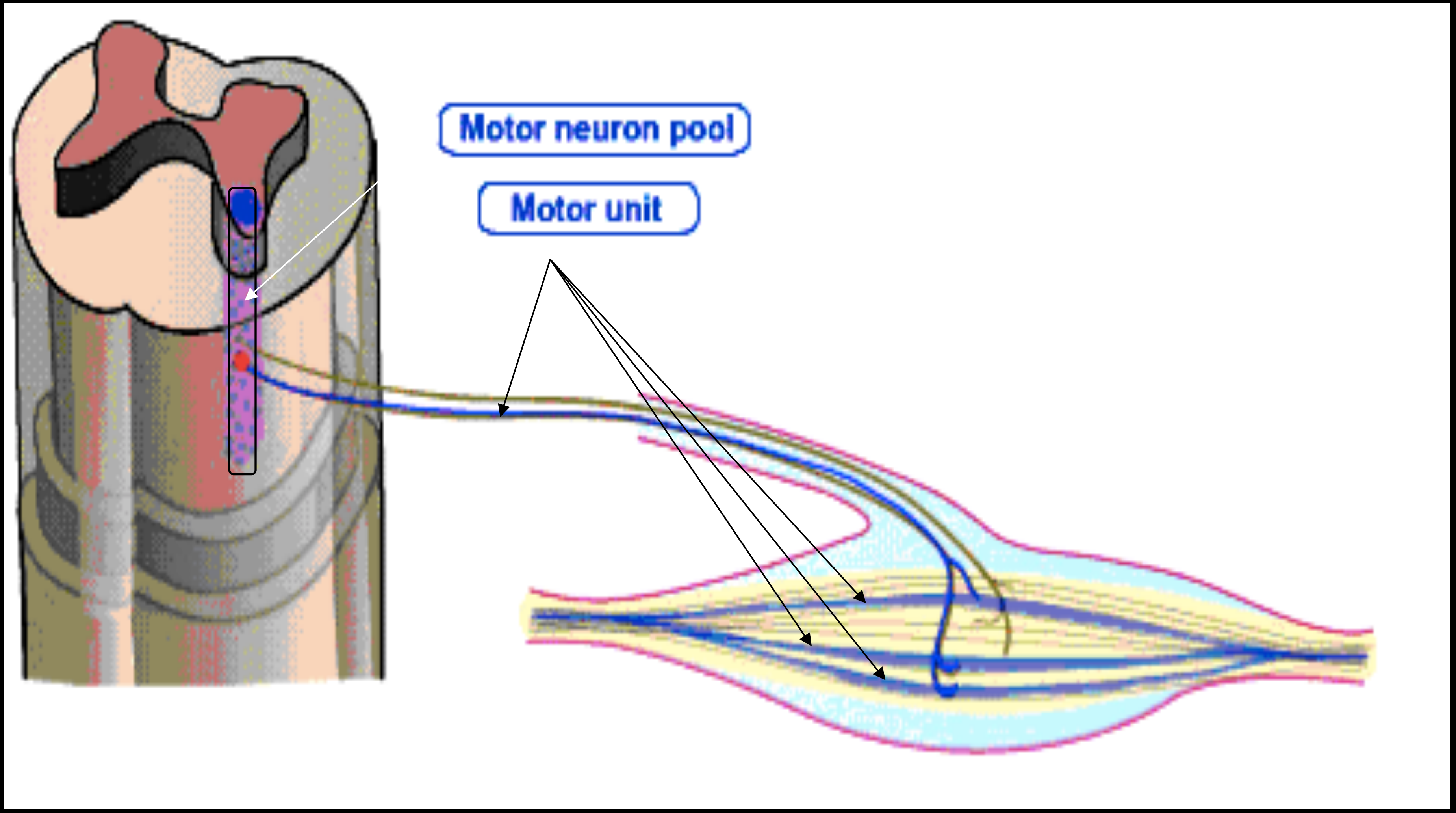
Motor Neuron Pool (Motor Nucleus)

The group of motor neurons that innervate an individual muscle

Motor Unit

An individual motor neuron and all the muscle fibers that it innervates

Motor Neuron Pool vs. Motor Unit



Motor Neuron Pool (Motor Nucleus)

The group of motor neurons that innervate an individual muscle

Motor Unit

An individual motor neuron and all the muscle fibers that it innervates

Innervation Ratio

The number of muscle fibers innervated by a single motor neuron

Control of muscle force I

Type of Motor Unit (MN + Muscle):

Slow twitch - Type I

Fast twitch - Type II

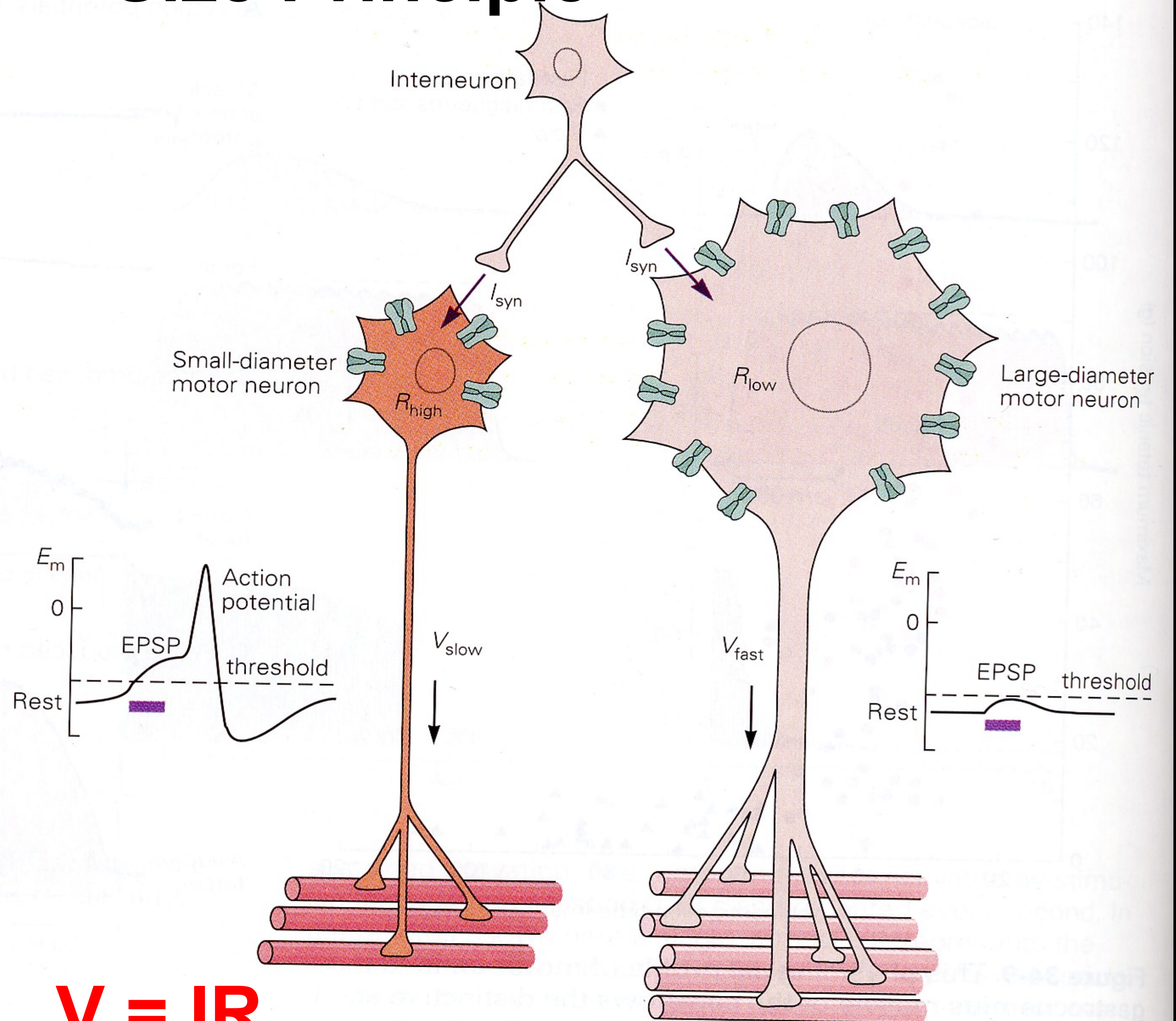
Determined by innervation!

Control of muscle force II

Size Principle: With increasing strength of input, motor neurons are recruited from smallest to largest

Rate Code: Increases in rate of action potentials of motor neuron cause increases in muscle force

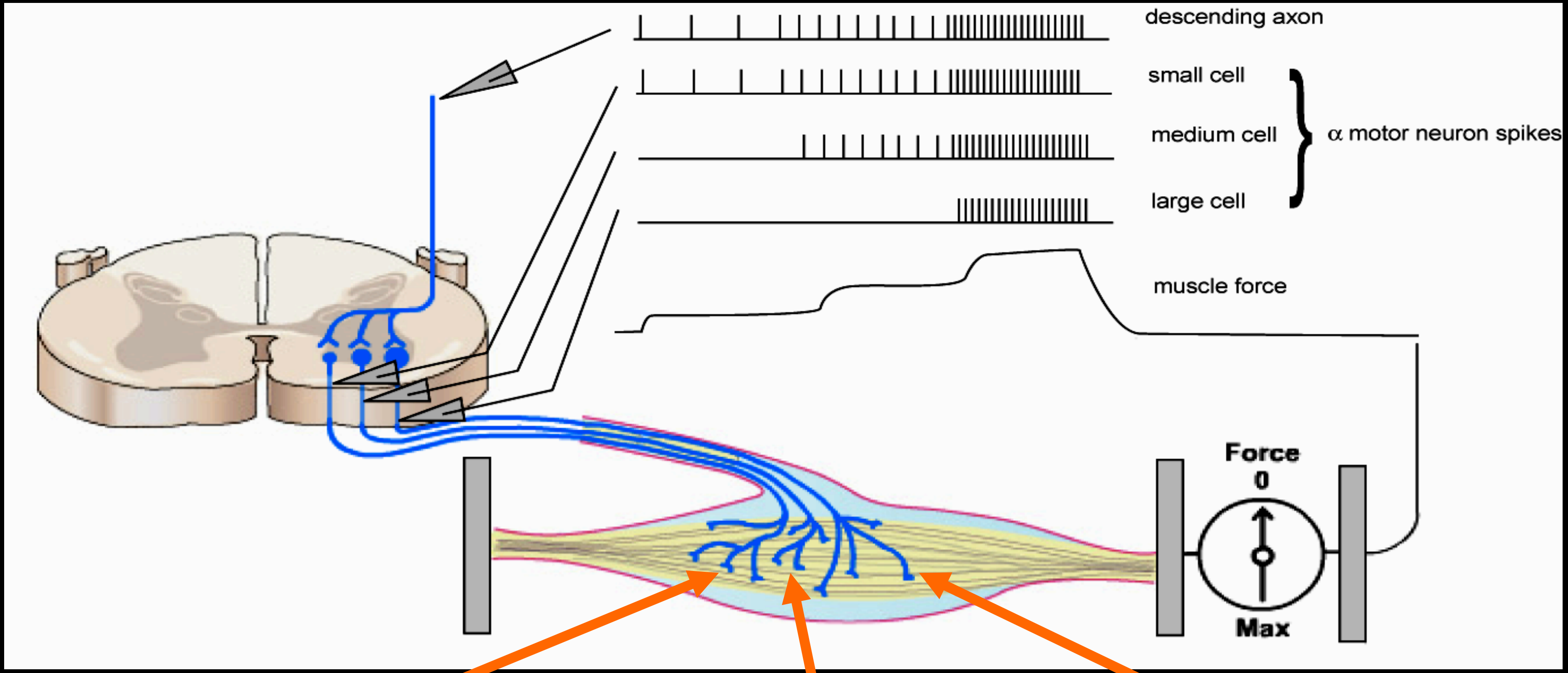
Size Principle



V = IR

From G. E. Loeb & C. Ghez (2000), in *Principles of Neural Science, 4th Edition* (Kandel, Schwartz, & Jessel, Eds.)

Size Principle



Small motor neurons innervate slow-twitch muscle fibers

Medium motor neurons innervate fast-twitch, fatigue-resistant muscle fibers

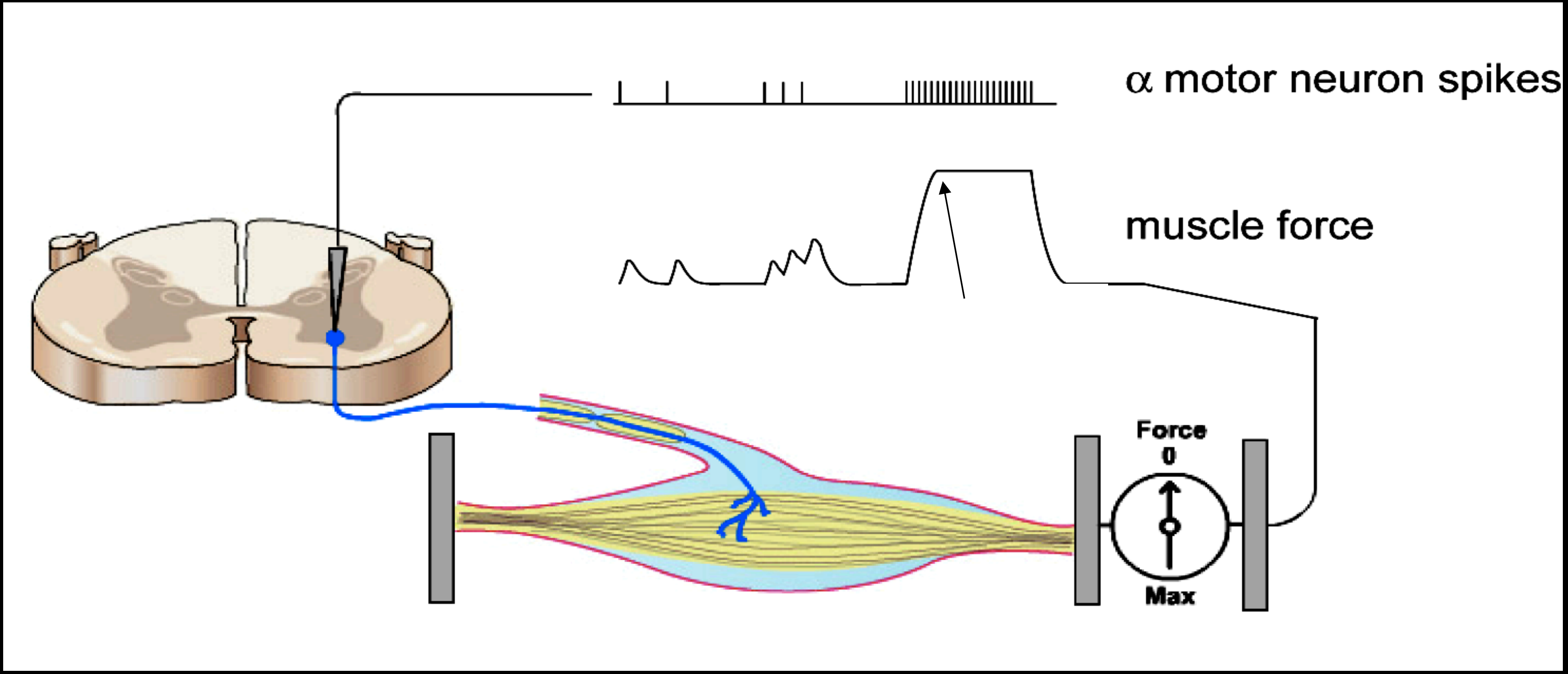
Large motor neurons innervate fast-twitch, fatigable muscle fibers

Control of muscle force

Size Principle (recruitment): With increasing strength of input, motor neurons are recruited from smallest to largest

Rate Code: Increases in rate of action potentials of motor neuron cause increases in muscle force

Rate Code



Proprioception

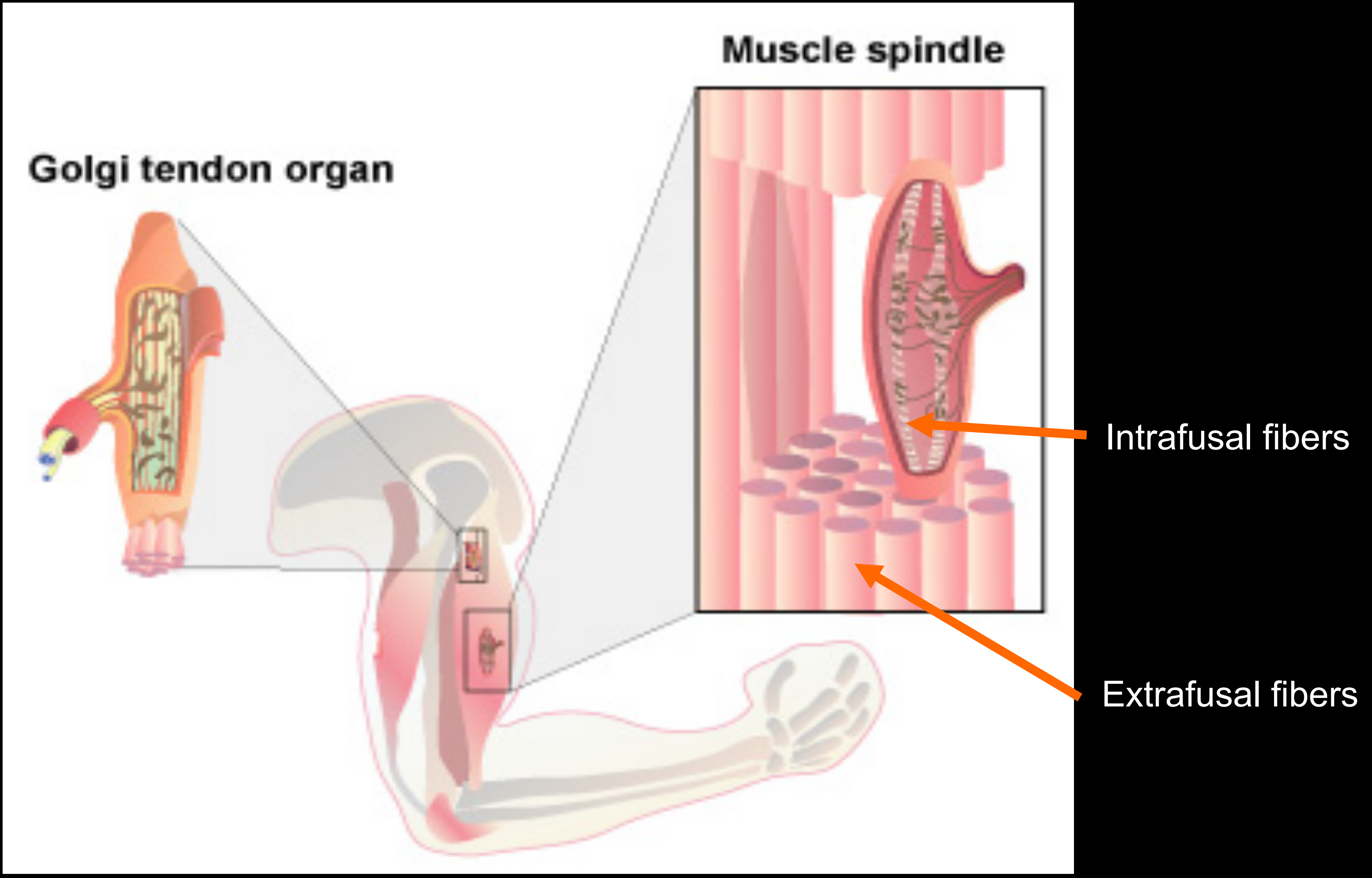
Specialized receptors provide information about muscle:

- length
- velocity (change in length)
- load (force)

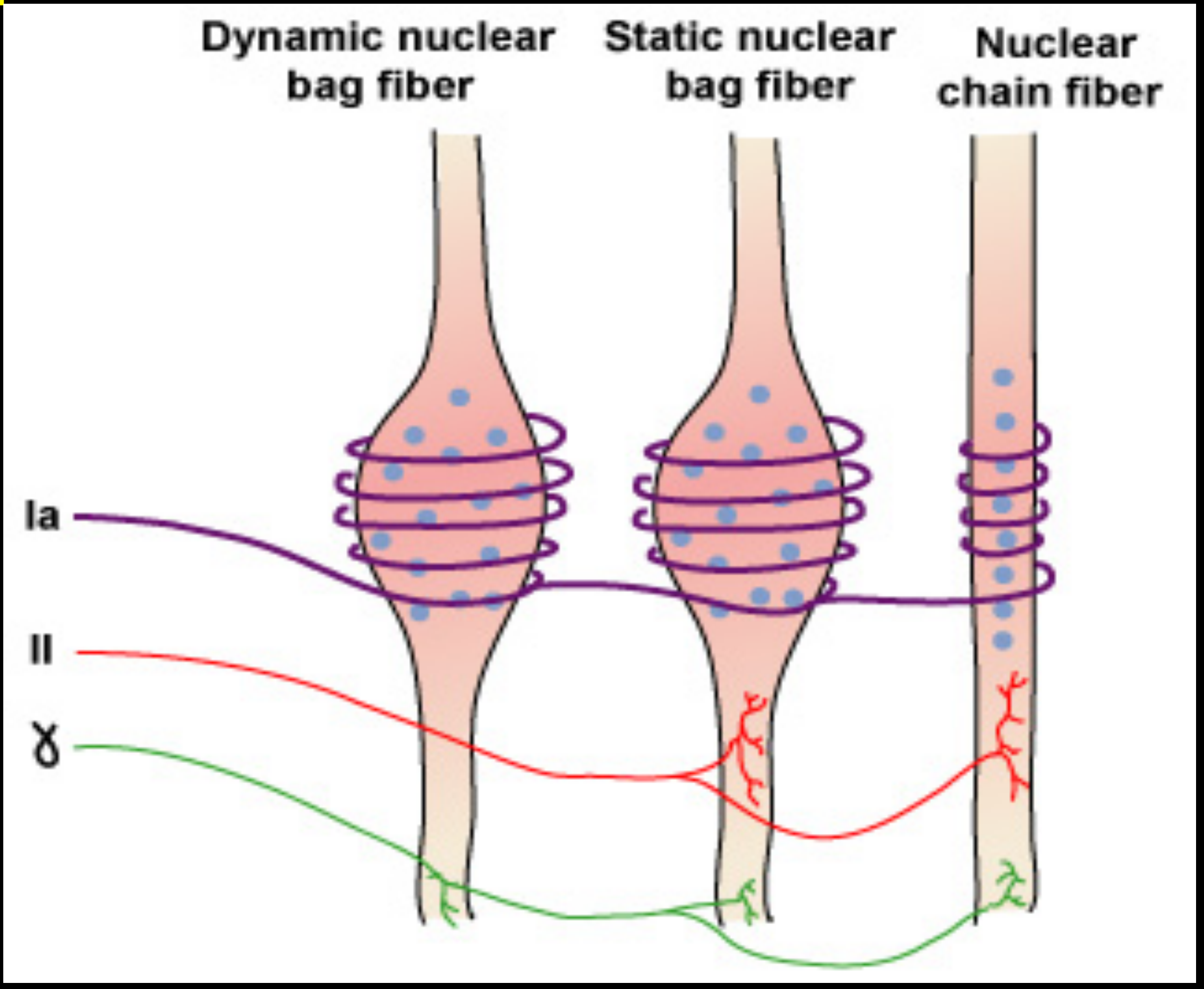
Receptors Involved in Proprioception

Muscle Spindles

Golgi Tendon Organ


Muscle spindle
Golgi tendon organ
Intrafusal fibers
Extrafusal fibers

Muscle Spindles are made of intrafusal muscle fibers



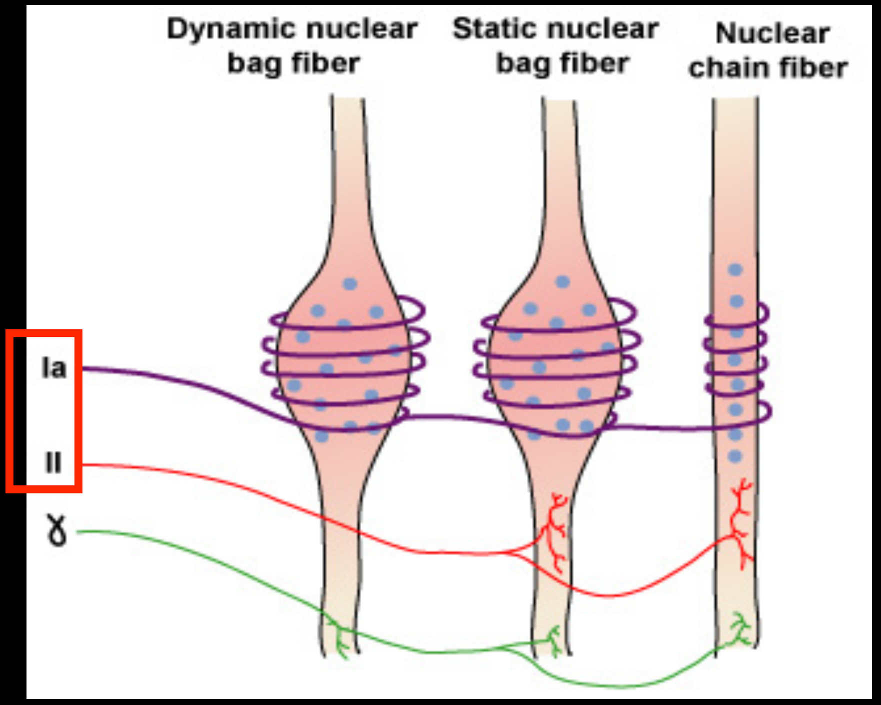
Typical muscle spindle = 1 dynamic nuclear bag fiber
1 static nuclear bag fiber
~ 5 nuclear chain fibers

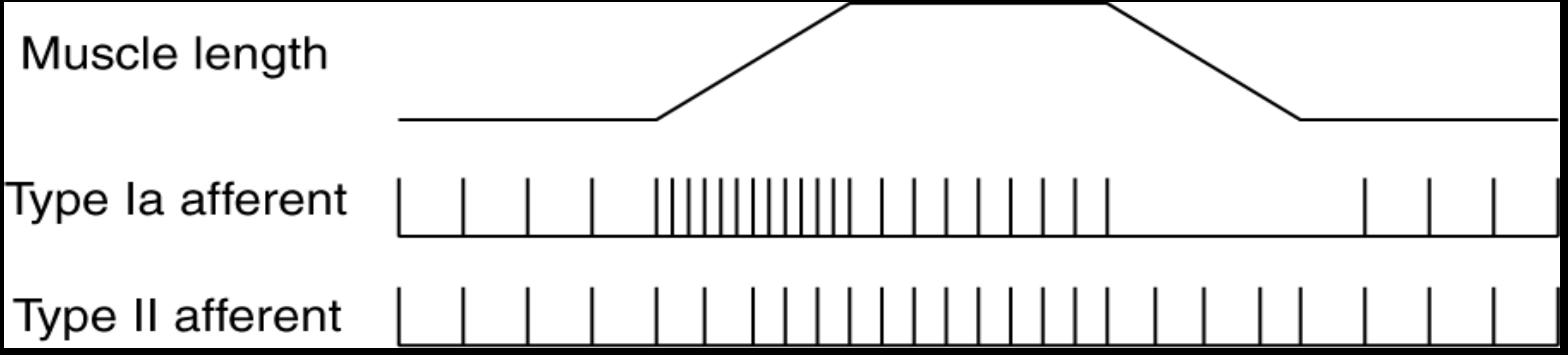
Sensory Fibers Involved in Proprioception

Muscle Spindles

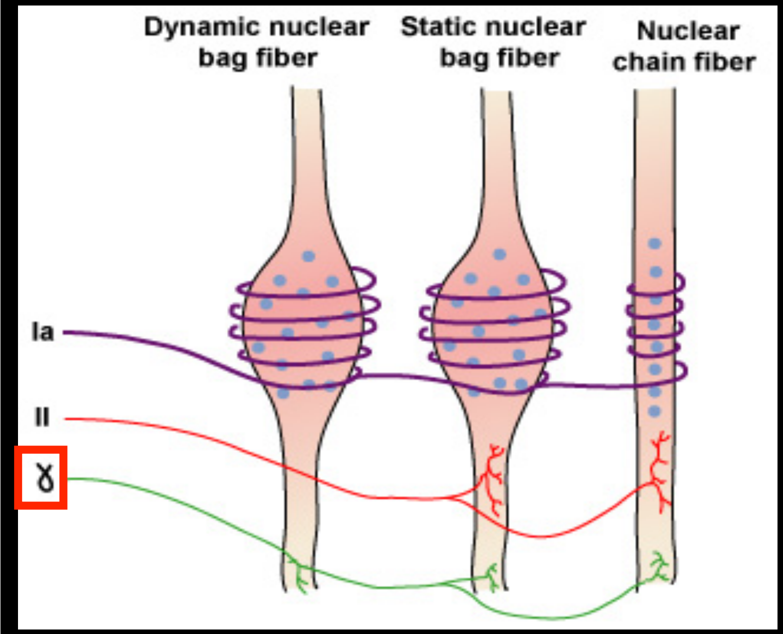
- Group Ia (primary): velocity and length
- Group II (secondary): length

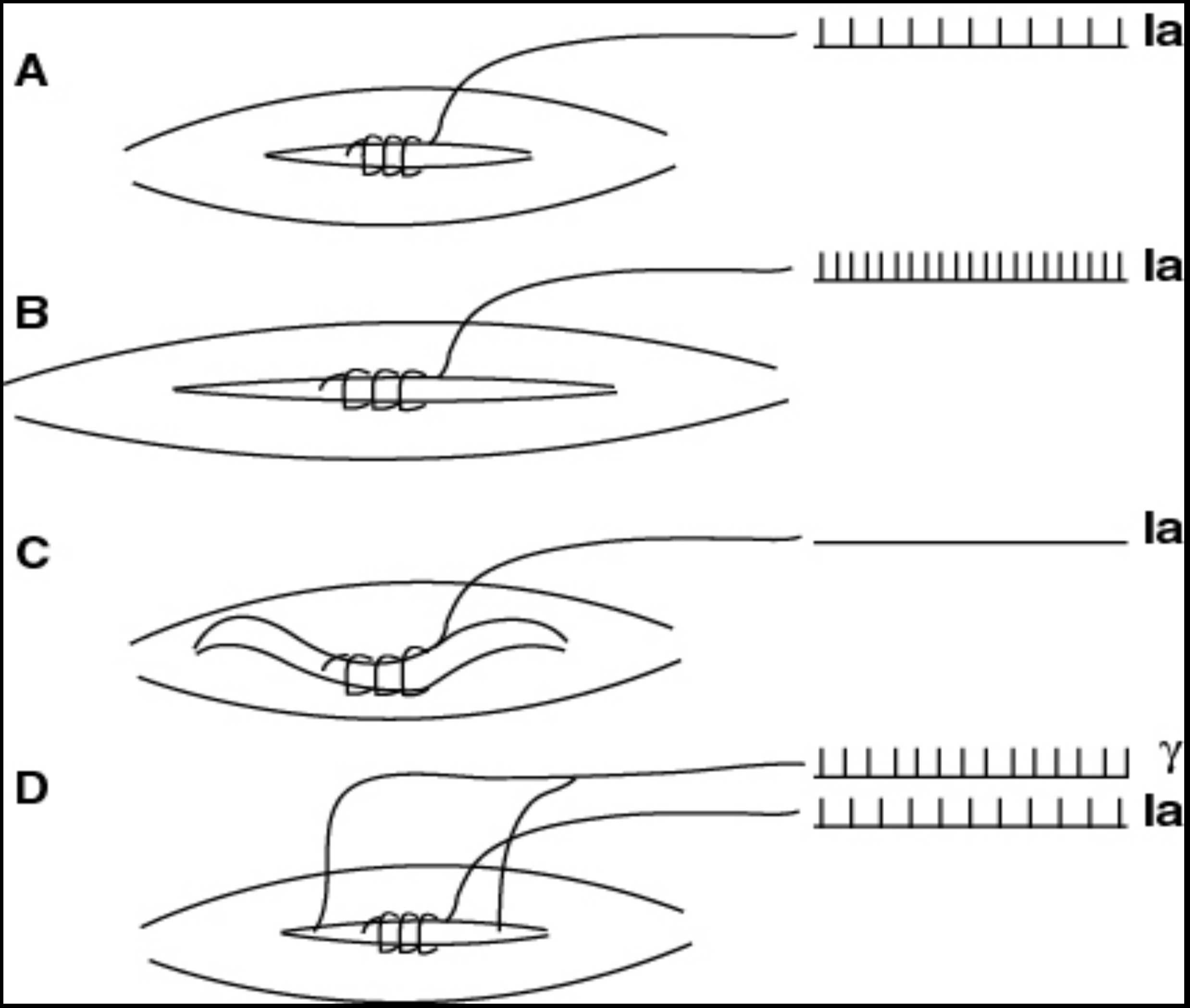
Type Ia afferents signal velocity and length, Type II afferents signal length only





Gamma motor neurons maintain sensitivity of muscle spindle

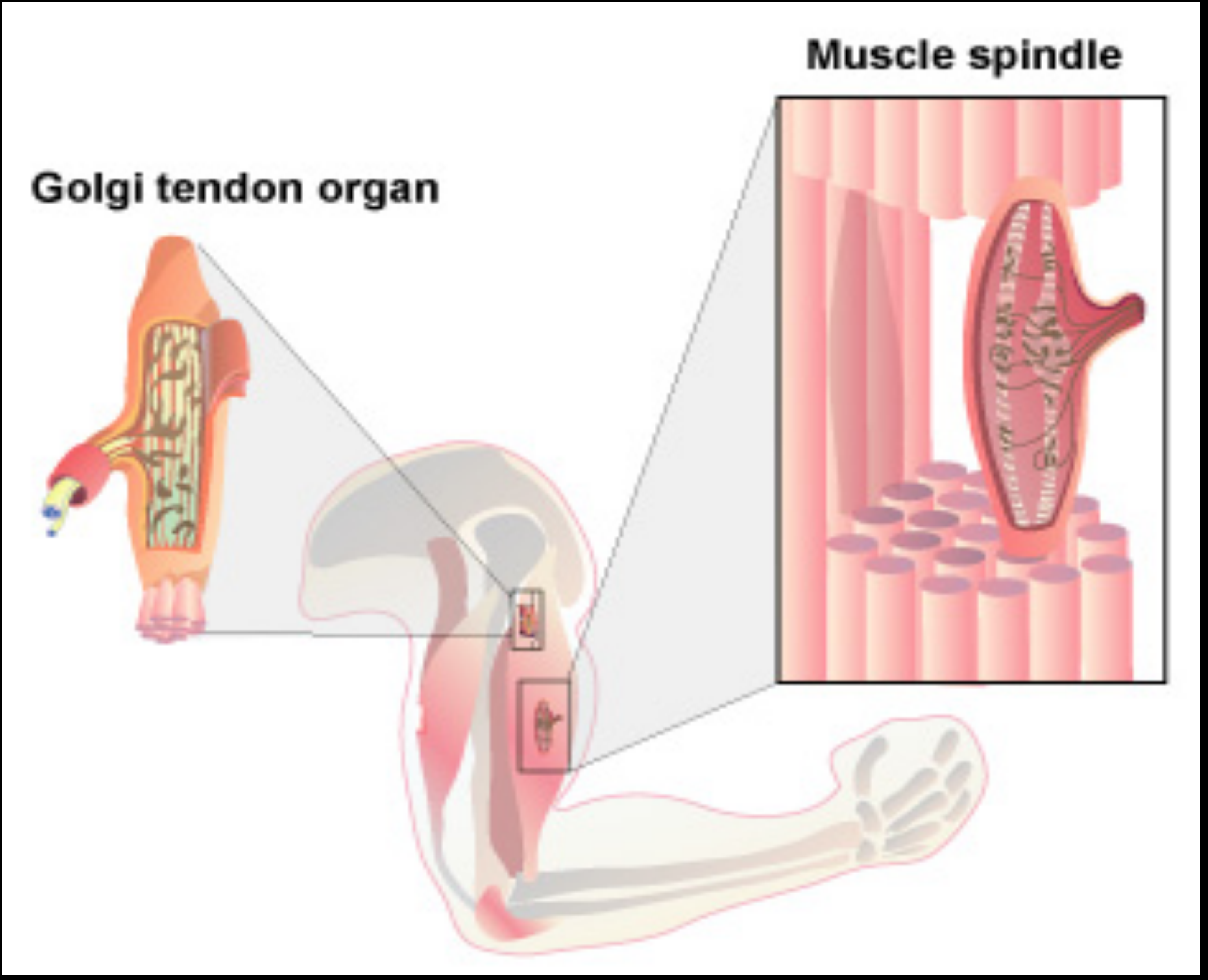




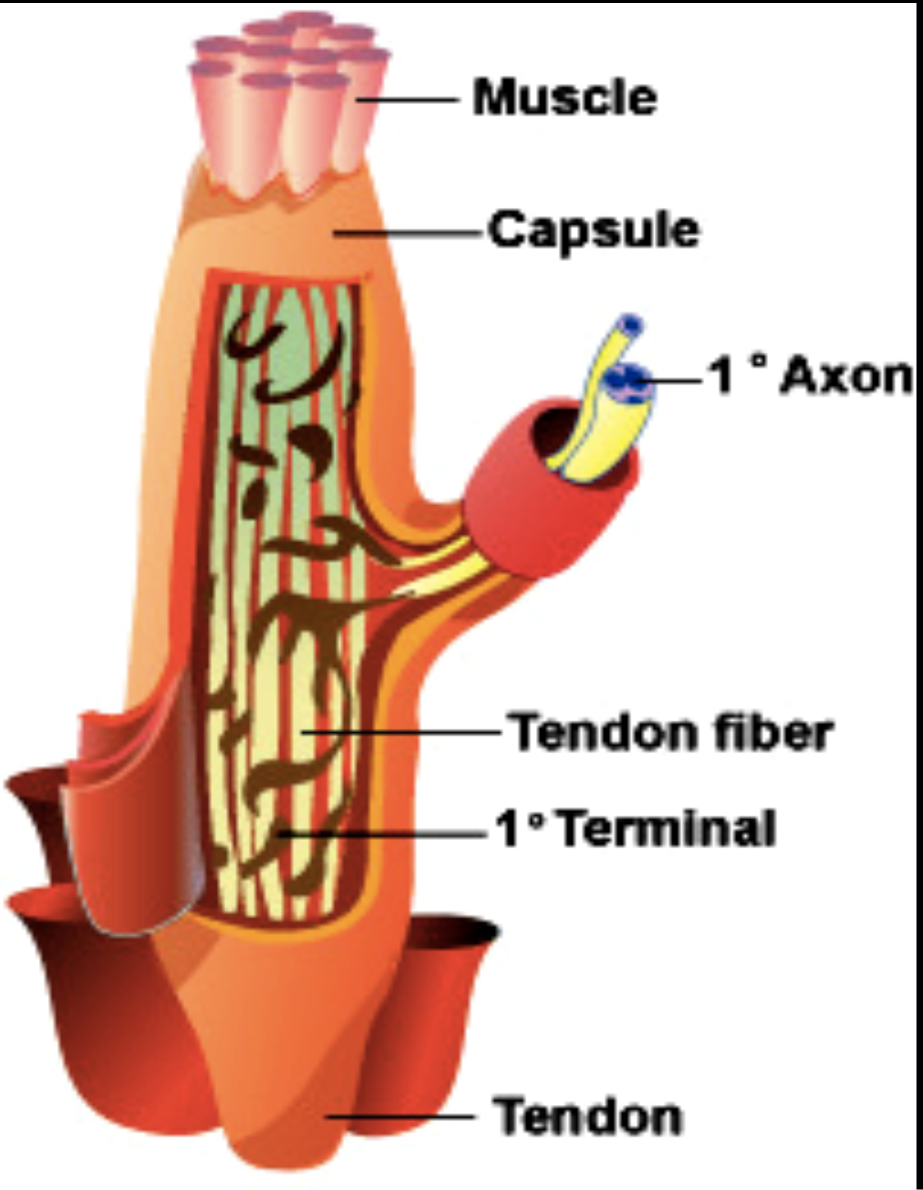
Receptors Involved in Proprioception

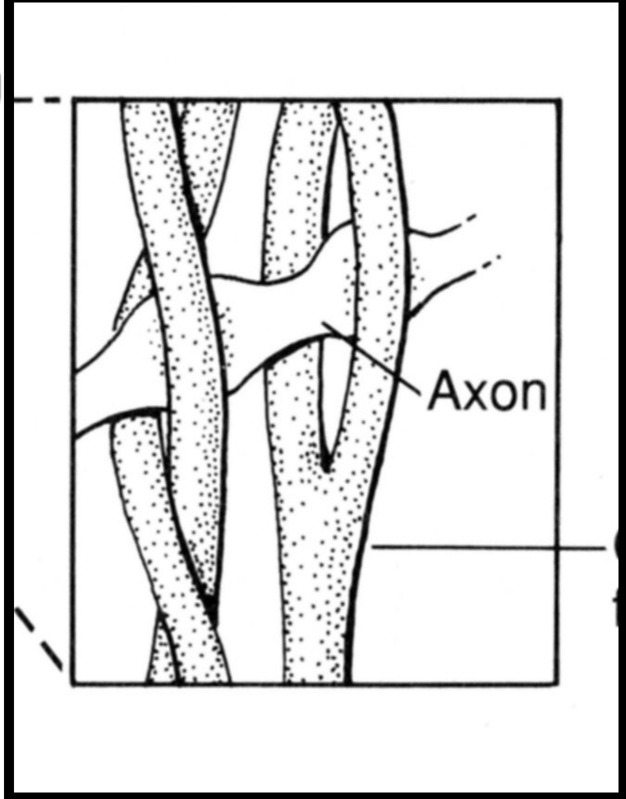
Muscle Spindles

Golgi Tendon Organs

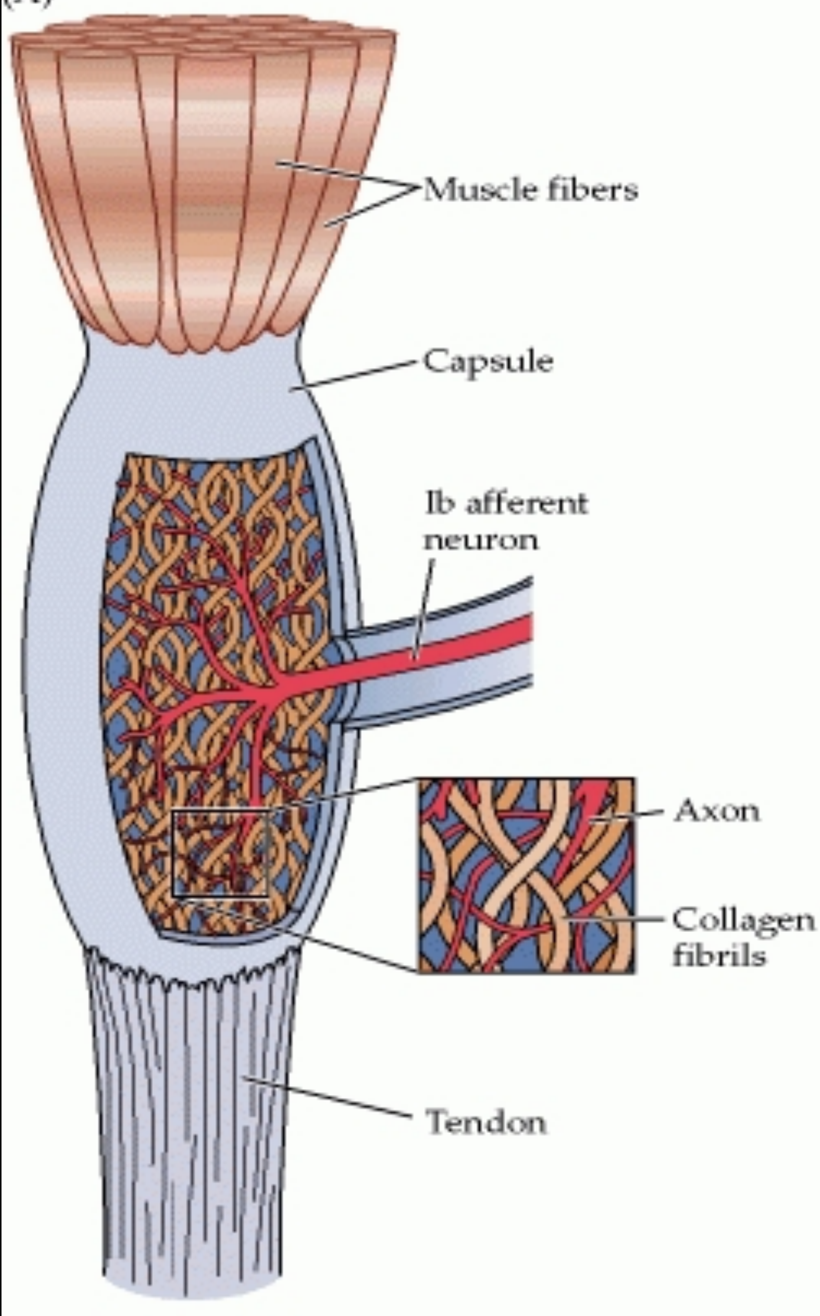

Golgi tendon organ
Muscle spindle

Golgi Tendon Organ

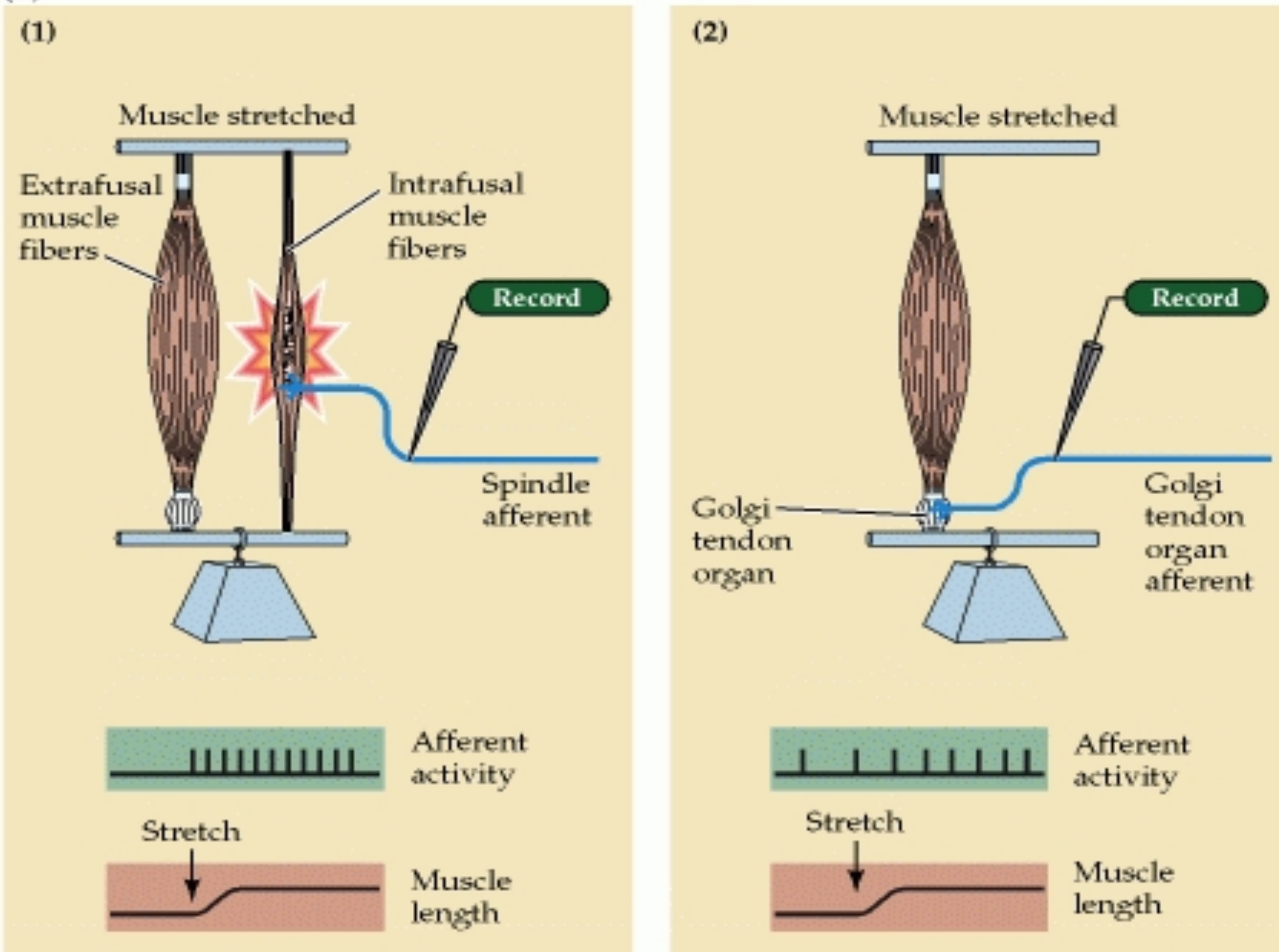




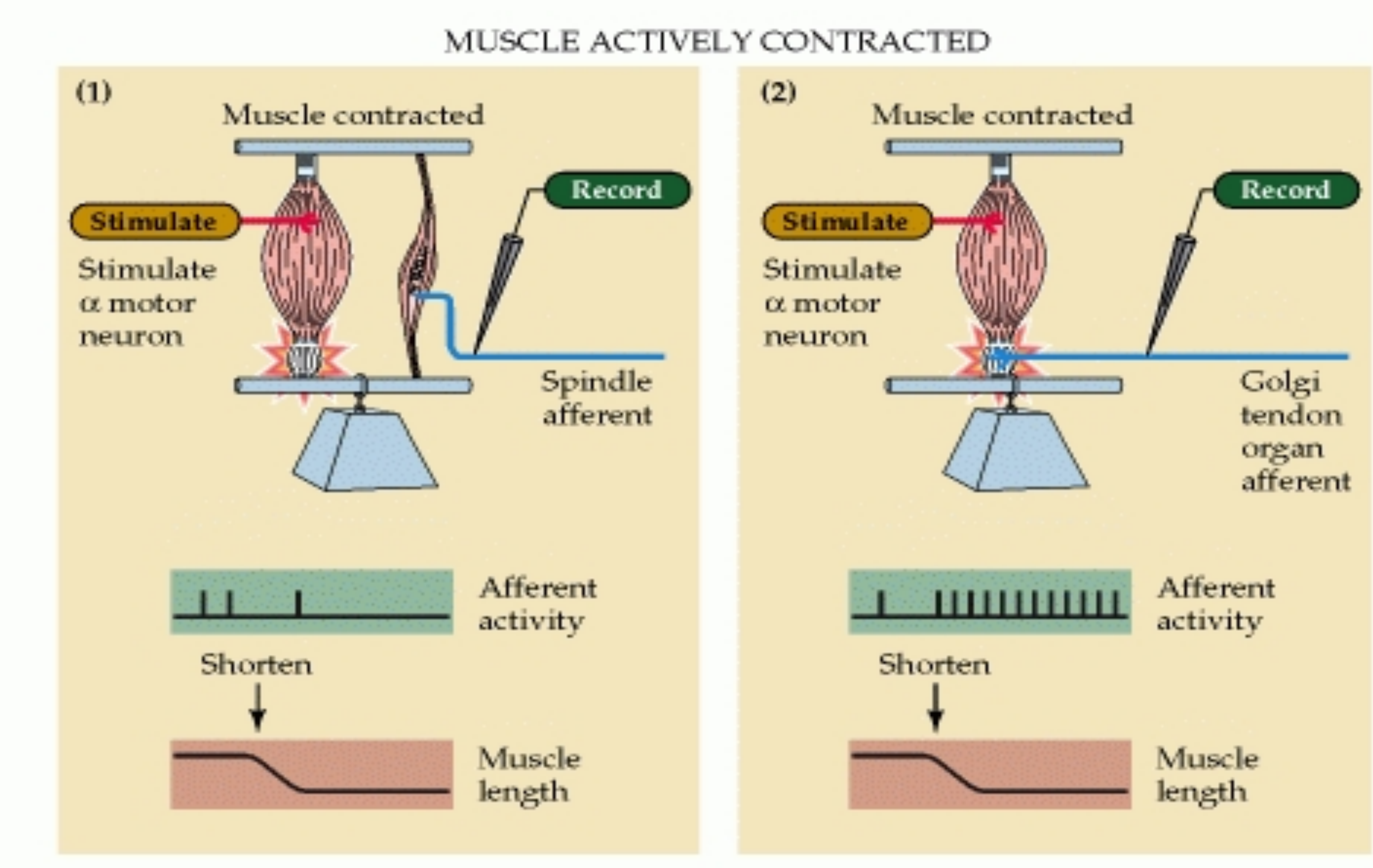
(A)


Muscle fibers
Capsule
Ib afferent neuron
Axon
Collagen fibrils
Tendon

(B) MUSCLE PASSIVELY STRETCHED



en


MUSCLE ACTIVELY CONTRACTED
(1)
Muscle contracted
Record
Stimulate
Stimulate
α motor
neuron
Spindle
afferent
Afferent
activity
Shorten
Muscle
length
(2)
Muscle contracted
Record
Stimulate
Stimulate
α motor
neuron
Golgi
tendon
organ
afferent
Afferent
activity
Shorten
Muscle
length

Sensory Fibers Involved in Proprioception

Muscle Spindles

Group Ia (primary): velocity and length
Group II (secondary): length

Golgi Tendon Organs

Group Ib: Tension or force

Questions

When is the muscle spindle afferent activated, during muscle stretch or during muscle contraction?

Questions

When is the gamma MN activated, during muscle stretch or muscle contraction?

Questions

When is the Golgi tendon organ afferent activated, during
muscle stretch or muscle contraction?

Questions

Activation of the gamma MN causes muscle contraction: true or false?

Spinal Anatomy

Reflexes

- Most reflexes are "involuntary" in the sense that they occur without the person willing them to do so, but <u>all</u> of them can be brought under "voluntary" control

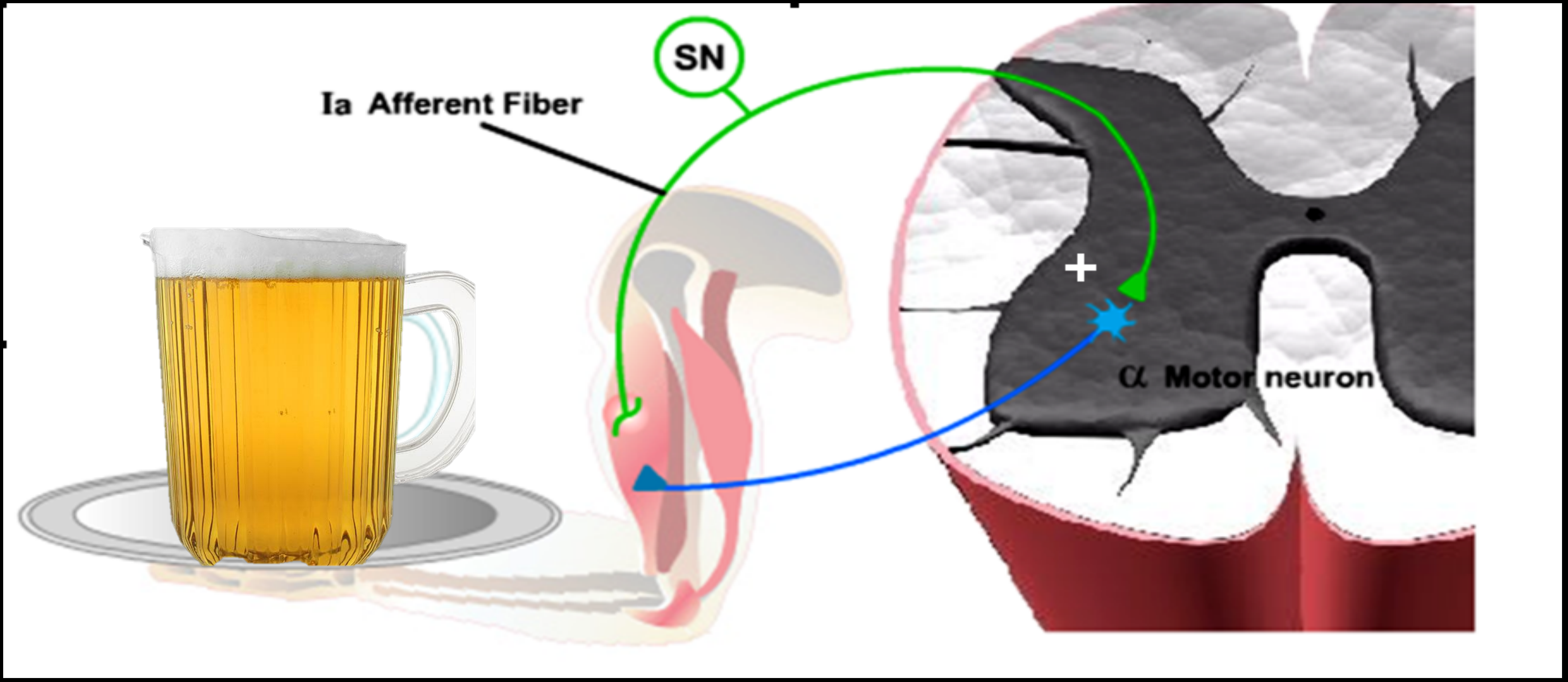
Spinal Reflexes

Myotatic reflex

[myo- + G. *tasis*, a stretching]
a.k.a. stretch reflex

Muscle spindles (Ia)
+ alpha motor neurons

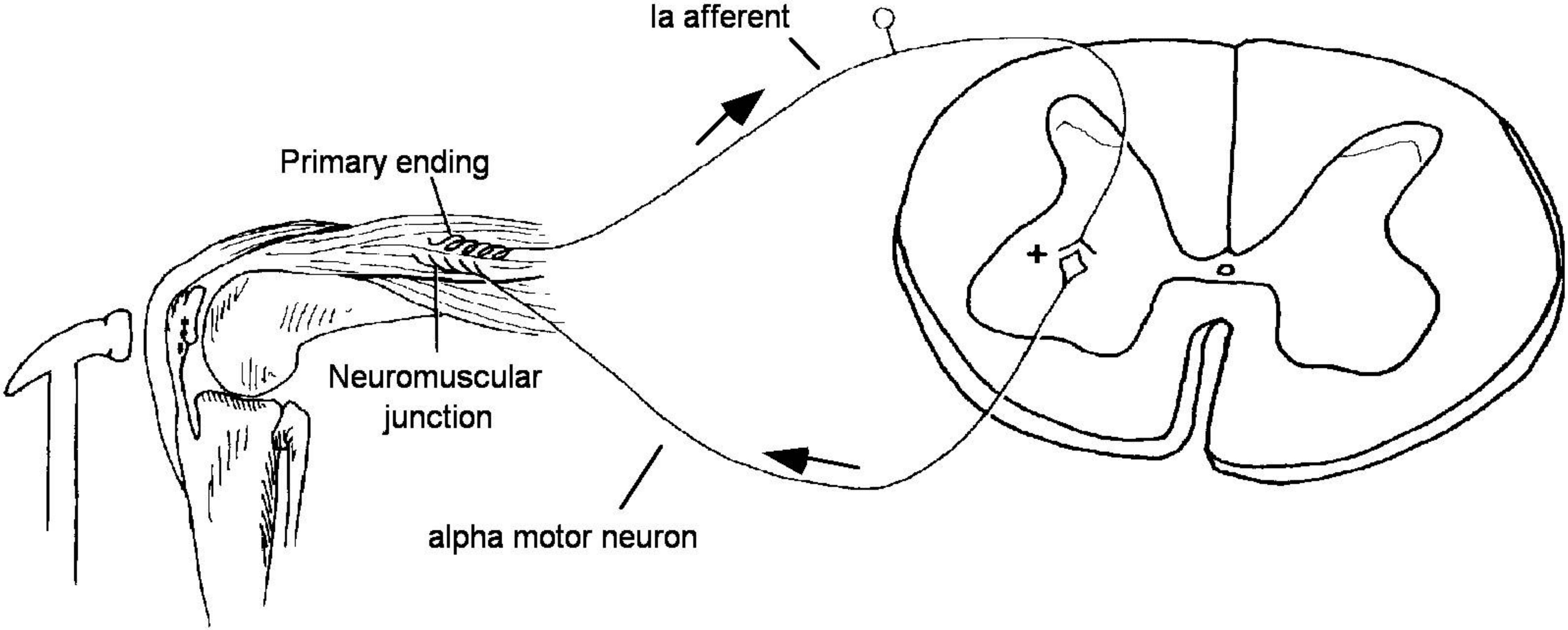
Myotatic reflex



Myotatic Reflex Important for Posture Maintenance

Continuous feedback from muscle spindles allows automatic postural maintenance and adjustments

“Knee-jerk” Response



From J. Nolte (1993) *The Human Brain, 3rd Edition*

Clinical correlate

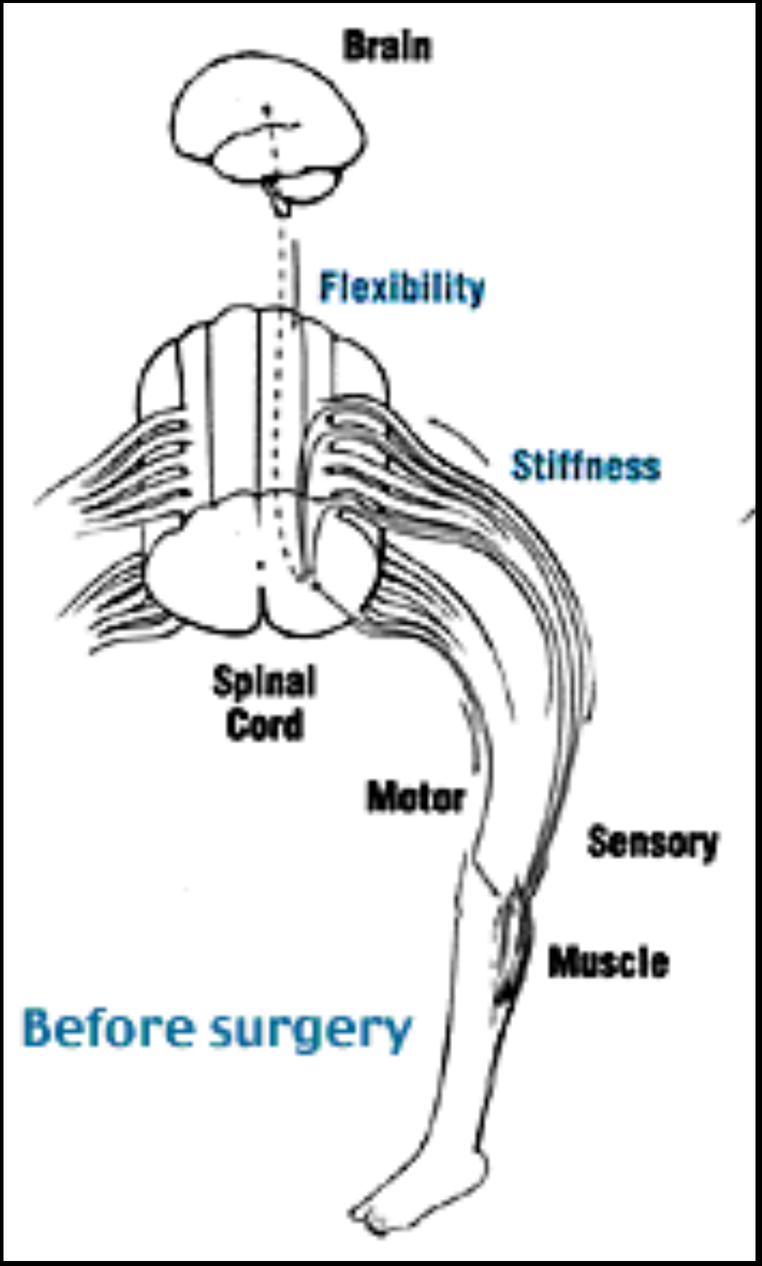
Cerebral Palsy

“palsy” = movement problem

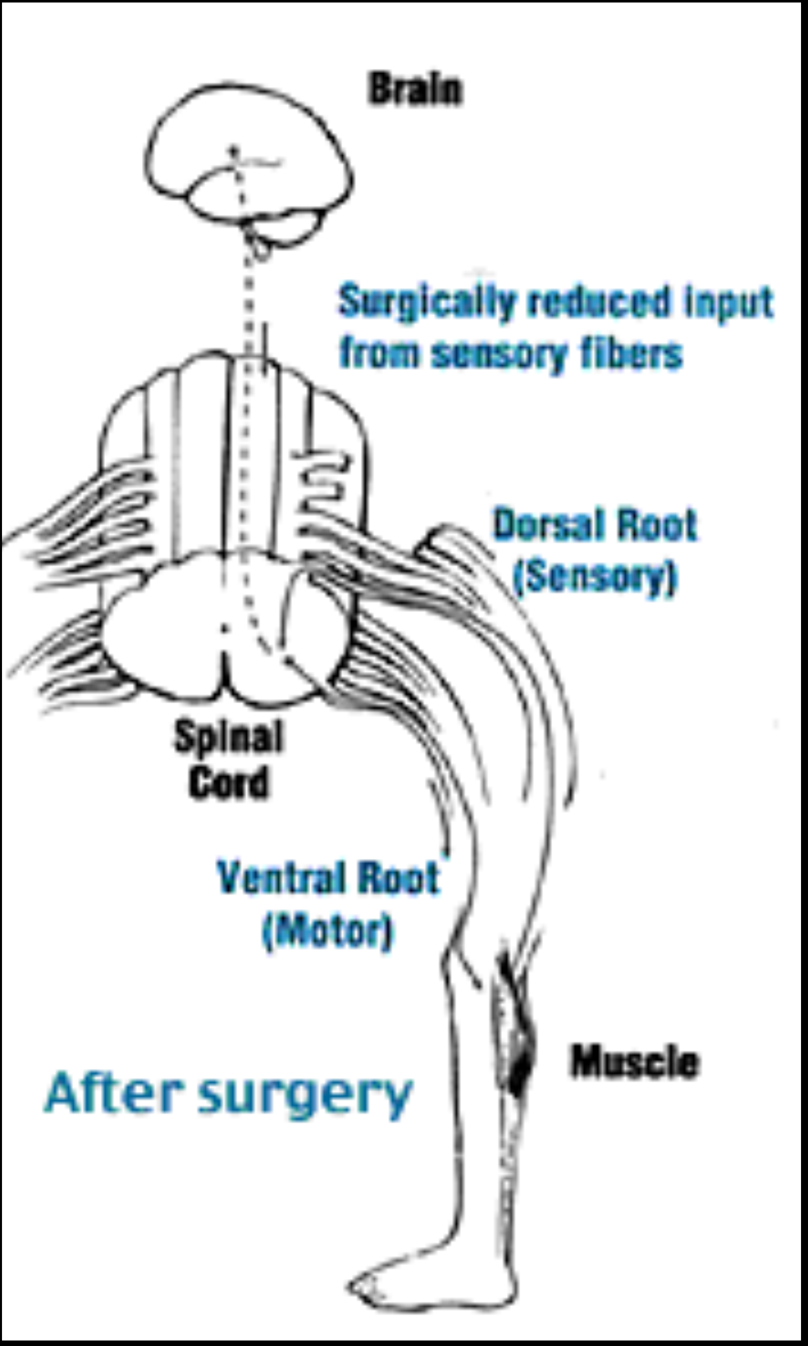
Common issue: spasticity

resistance of the muscle to passive lengthening in its most relaxed state.

Dorsal rhizotomy



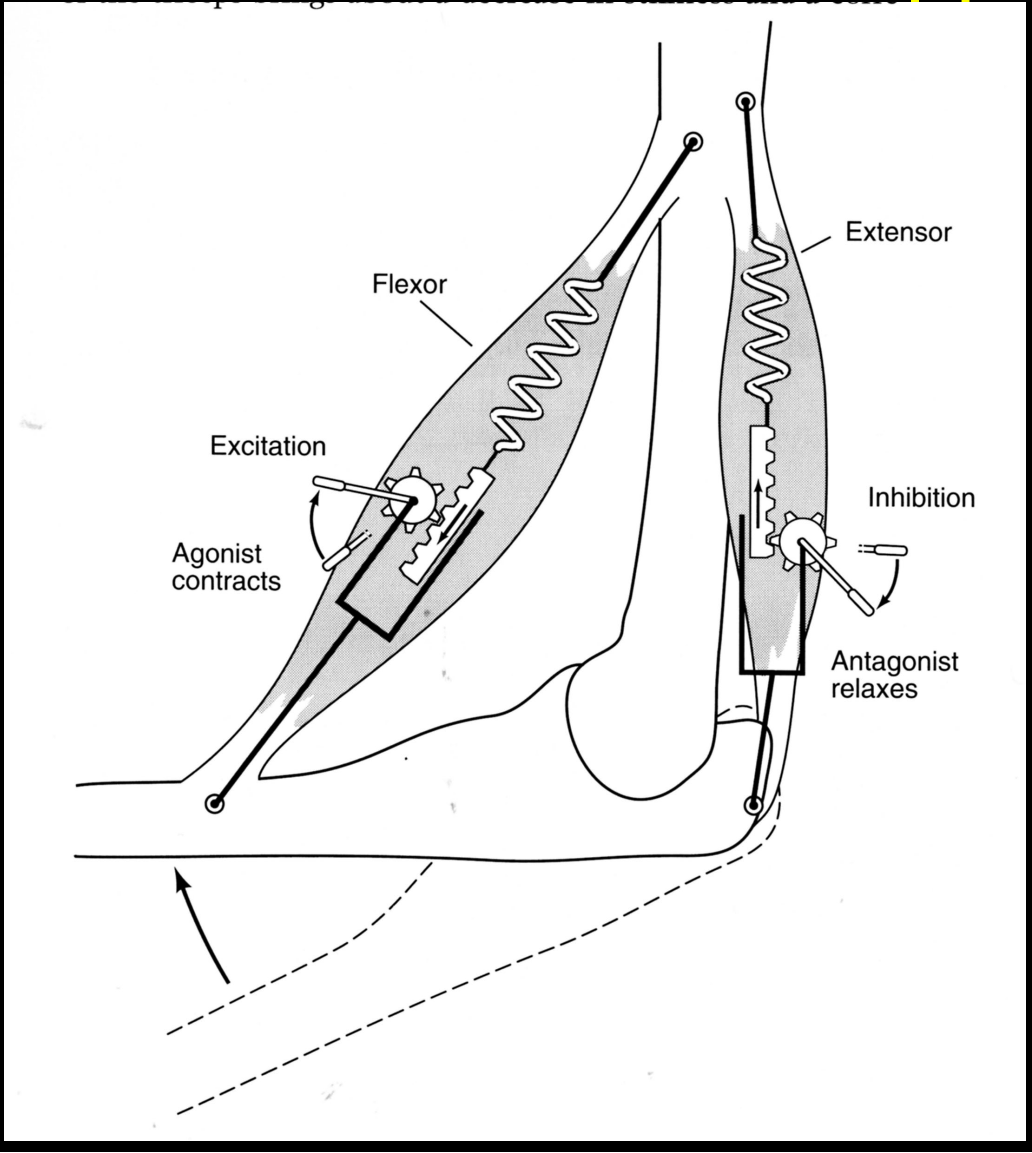
Dorsal rhizotomy



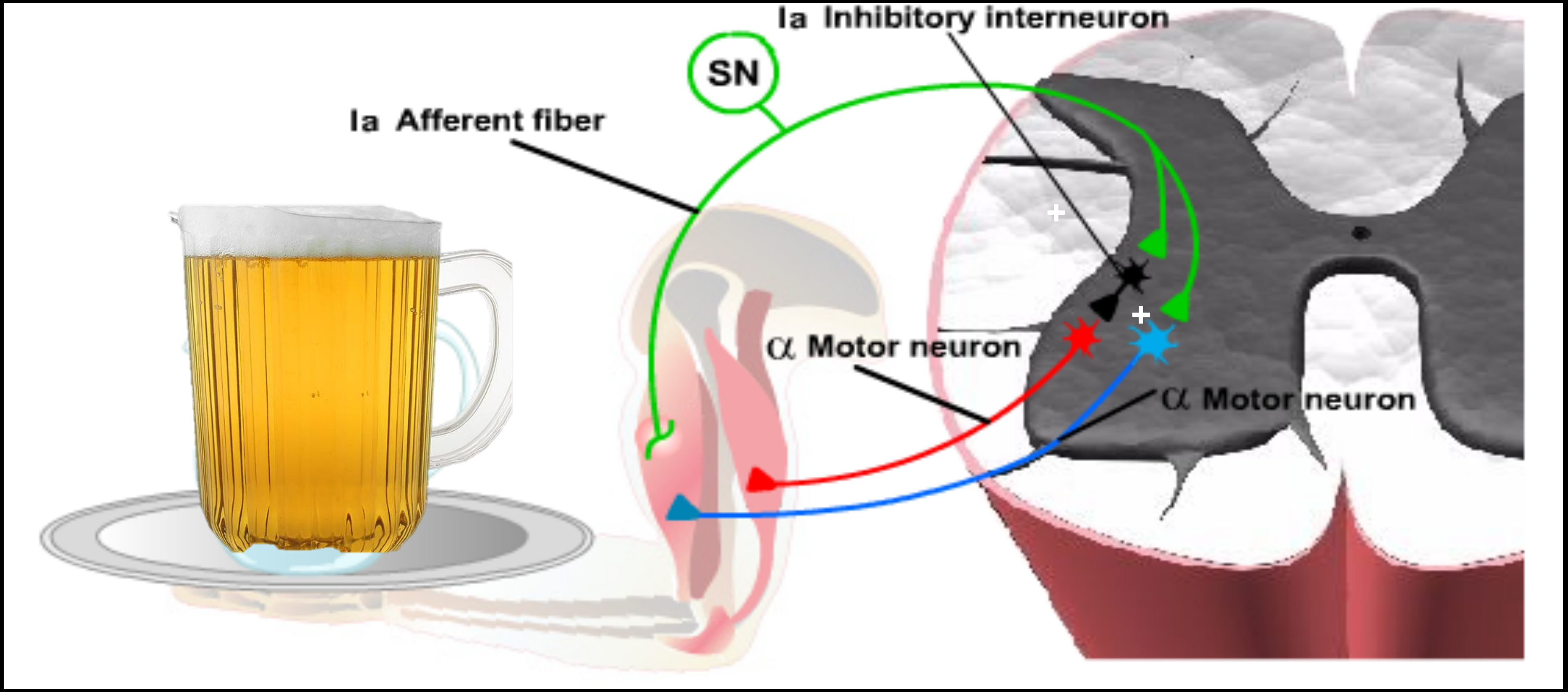
Reciprocal reflexes

Reciprocal inhibition in the stretch reflex

Flexor and extensor in opposition



Reciprocal inhibition in the stretch reflex



Spinal Reflexes

Myotatic reflex

Muscle spindles (Ia)

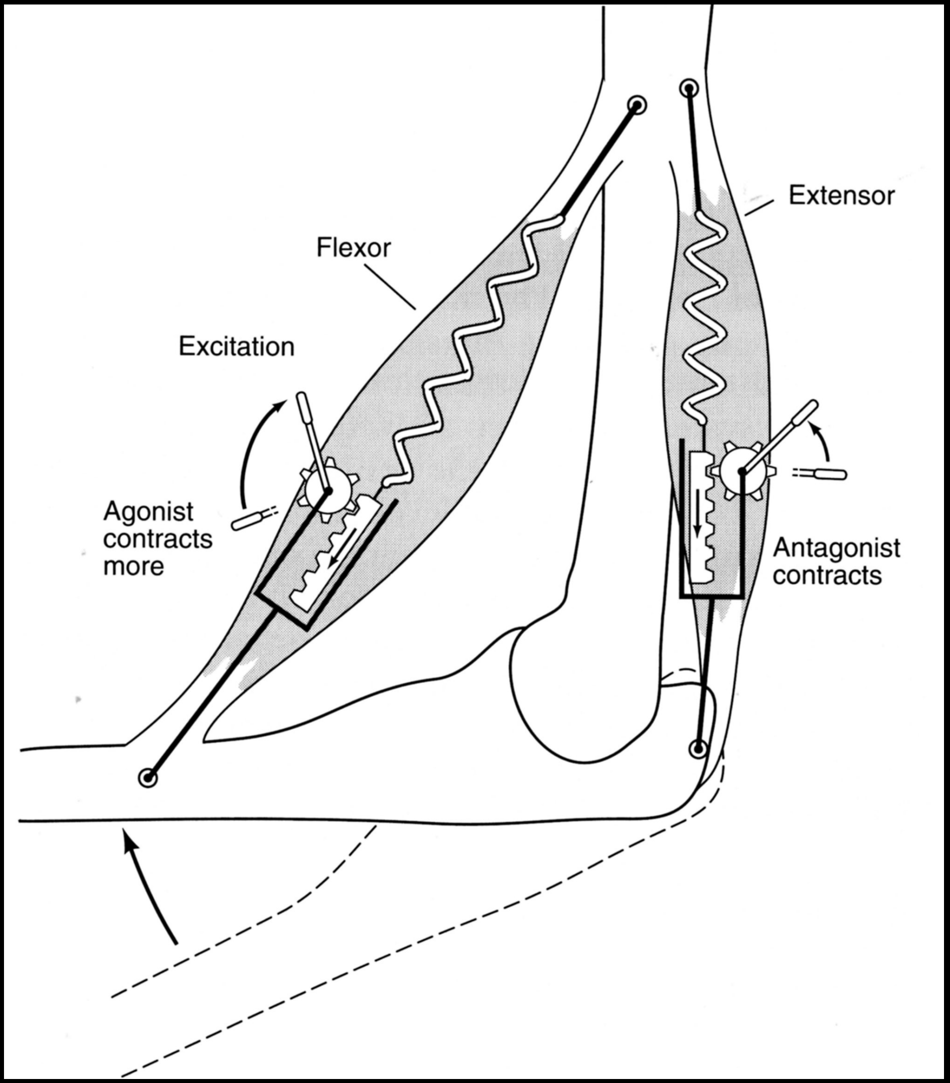
+ alpha motor neurons

Autogenic inhibition

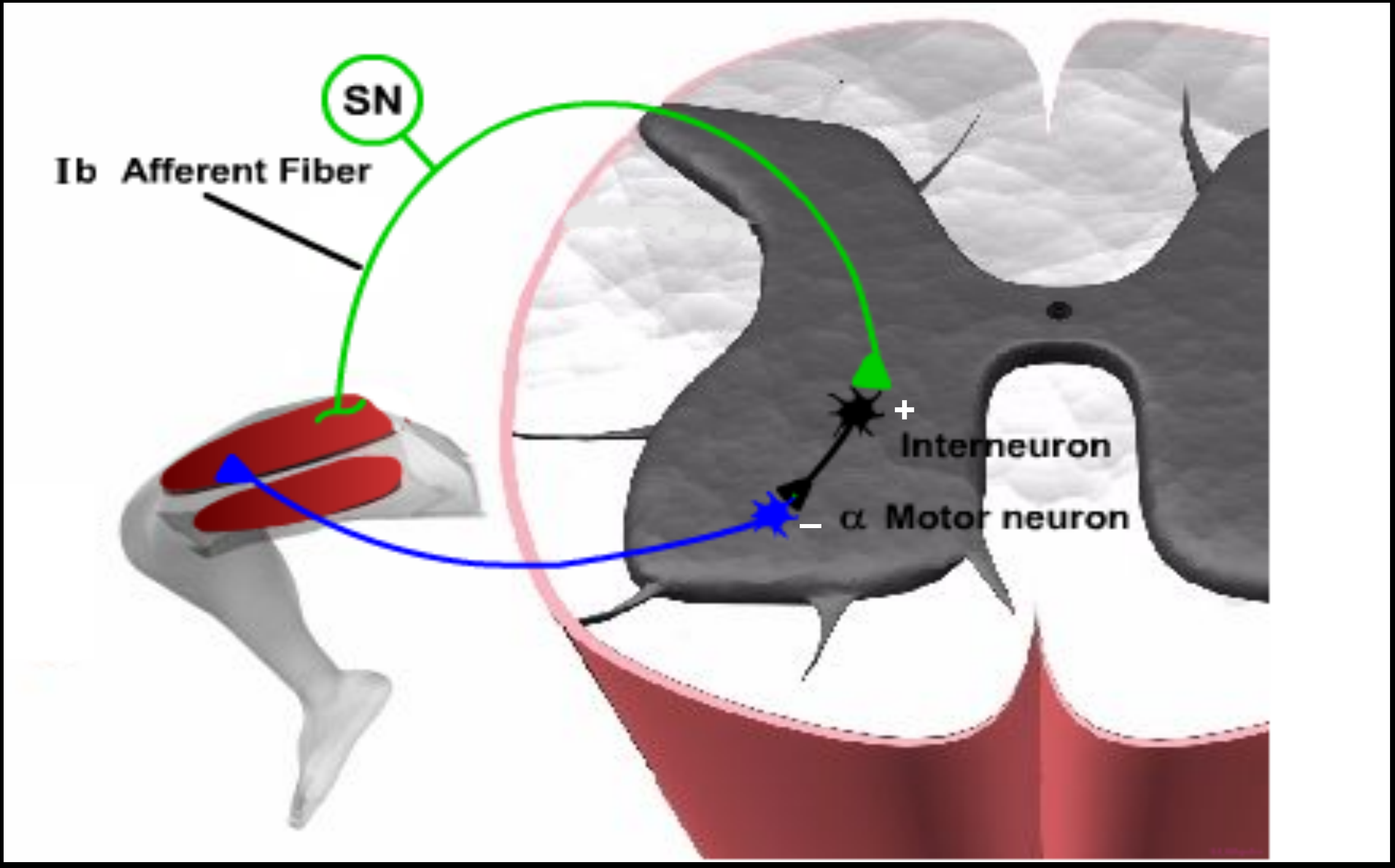
Golgi tendon organs (Ib)

- alpha motor neurons

Flexor and extensor: co-contraction



Autogenic Inhibition

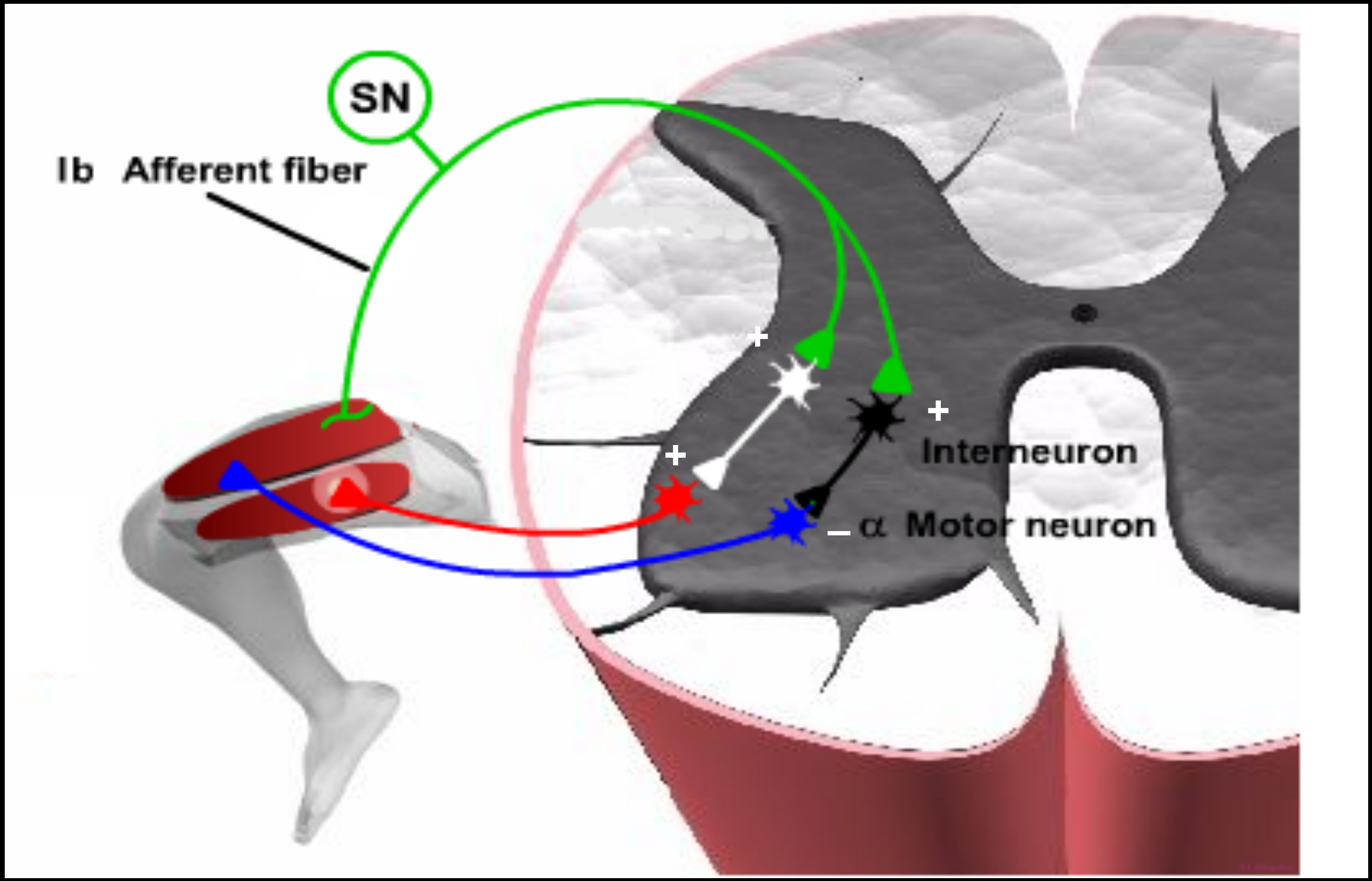


Reciprocal reflexes

Reciprocal inhibition in the stretch reflex

Reciprocal excitation in the autogenic inhibition reflex

Reciprocal excitation in the autogenic inhibition reflex



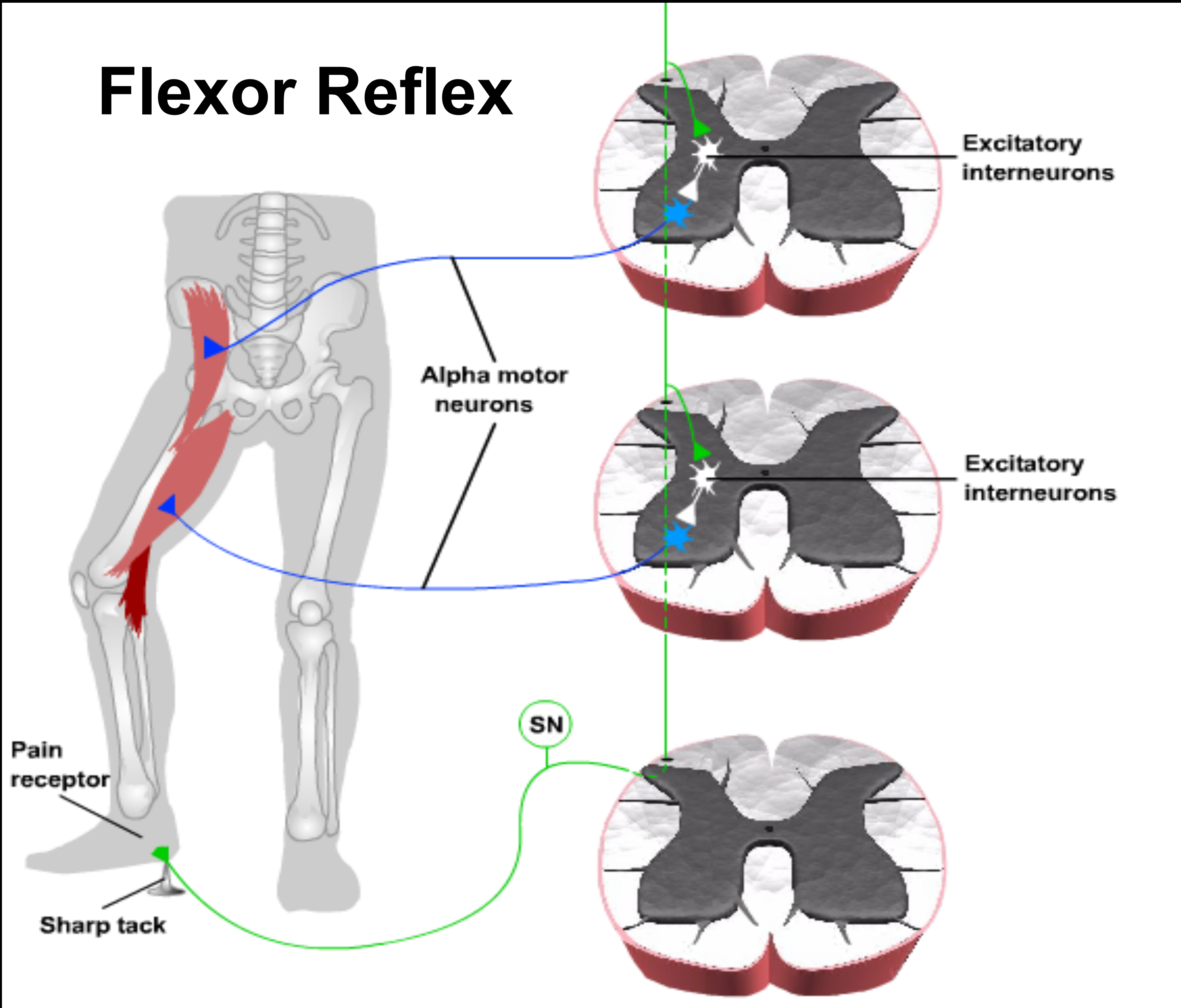
Flexor and crossed extension reflexes

Flexor reflex

Cutaneous and nociceptive receptors (II, III, and IV)

+ alpha motor neurons

Flexor Reflex



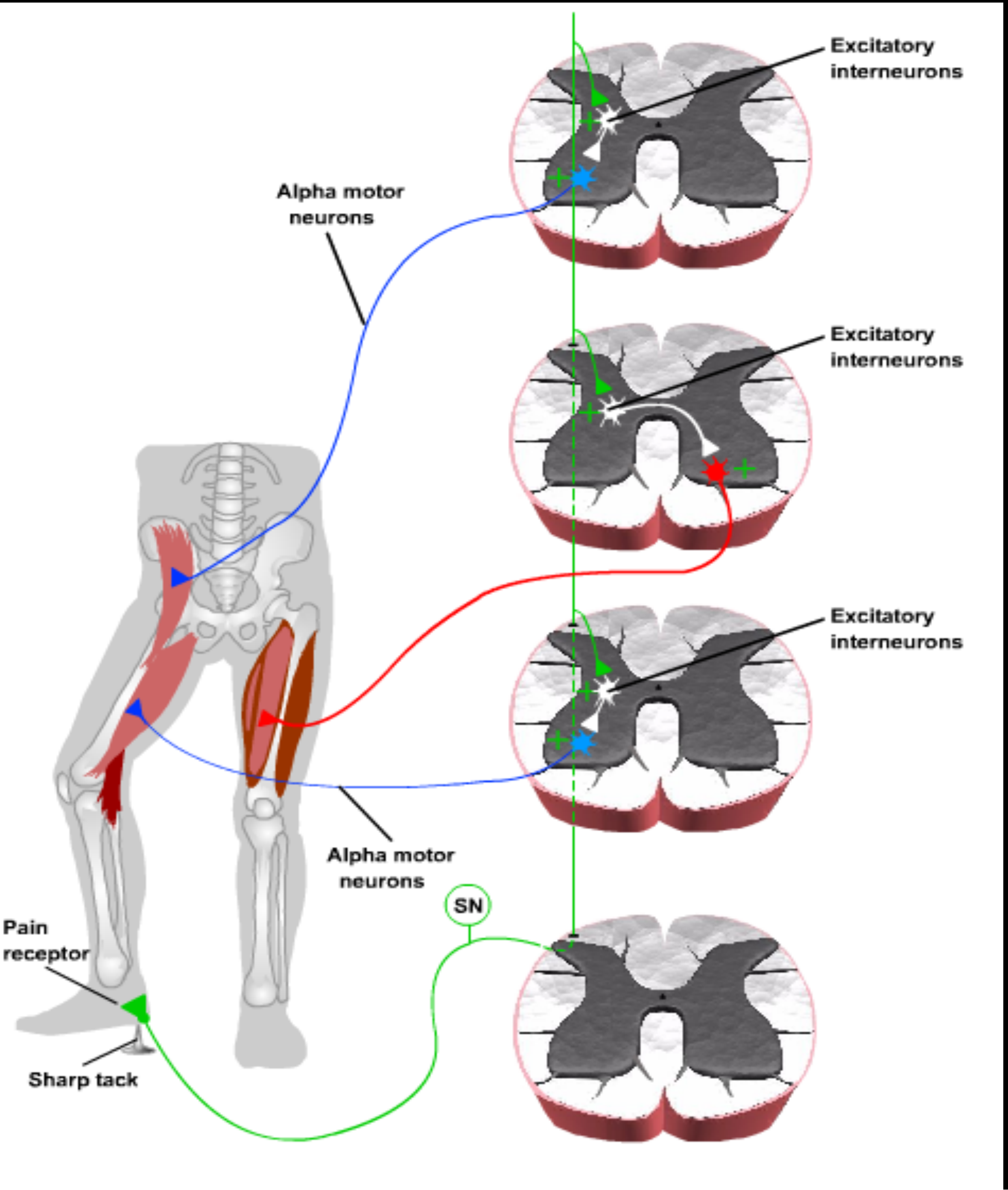
Flexor and crossed extension reflexes

Flexor reflex
Cutaneous and nociceptive receptors (II, III, and IV)
+ alpha motor neurons

Reciprocal inhibition in the flexor reflex

Crossed extension reflex

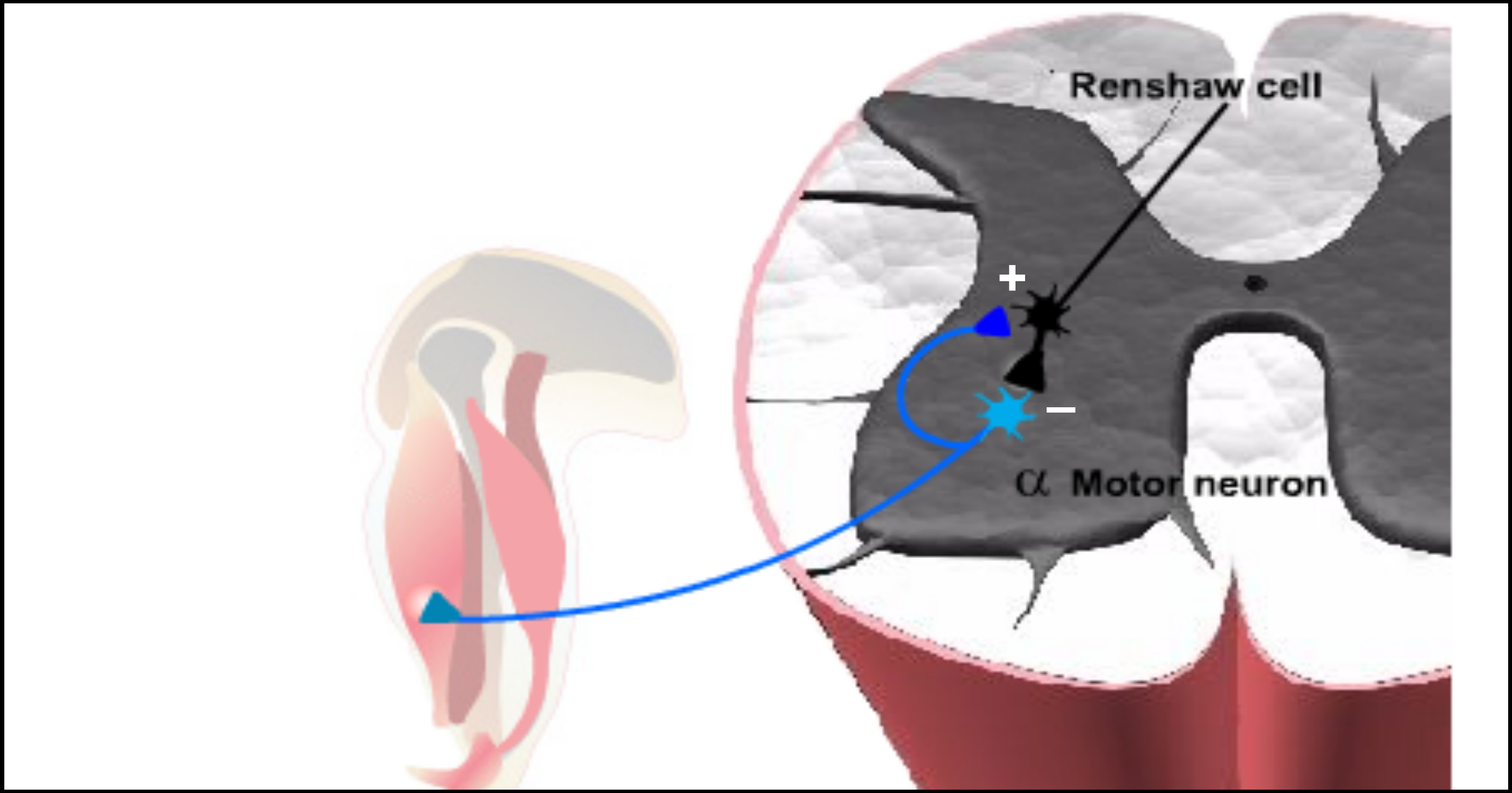
Crossed extension reflex



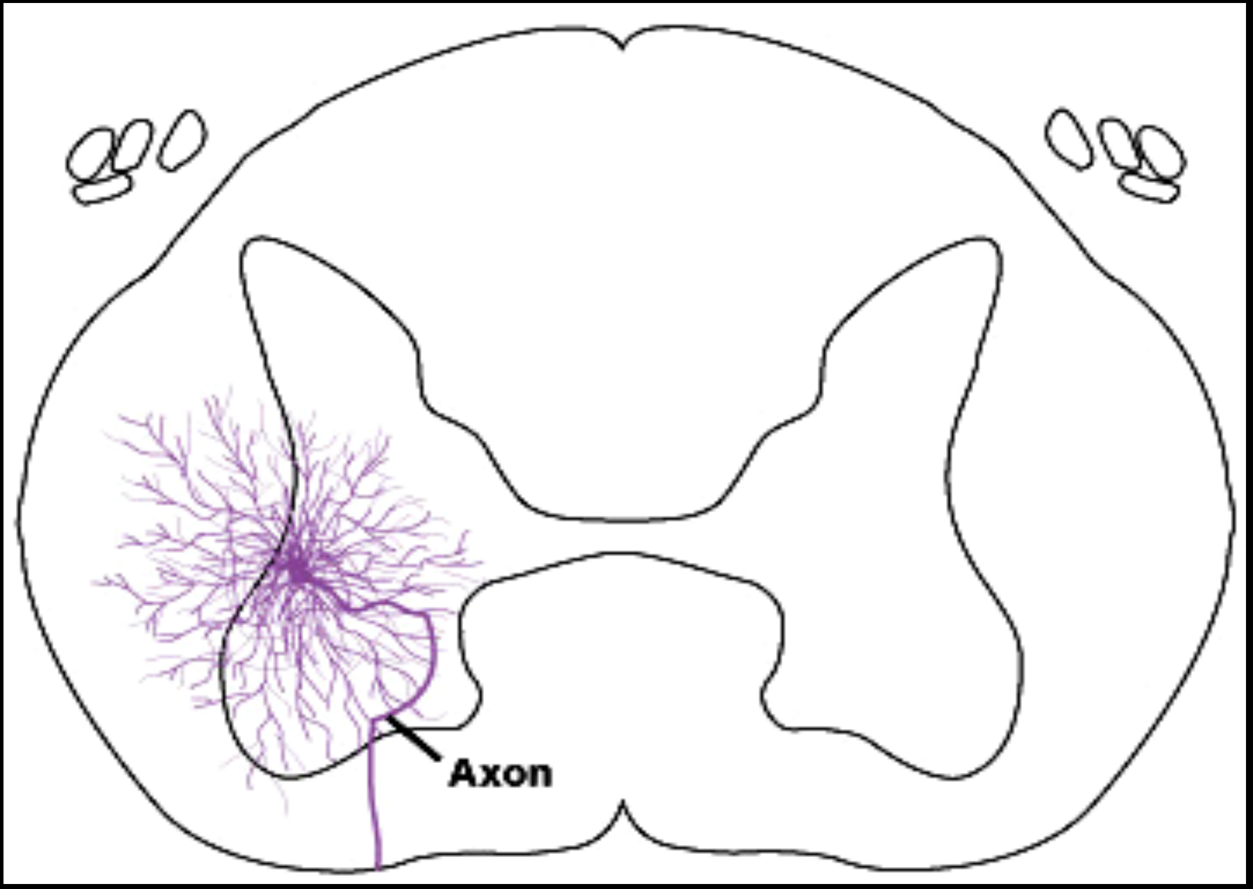
Recurrent inhibition of motor neurons

Renshaw Cell

Renshaw cell



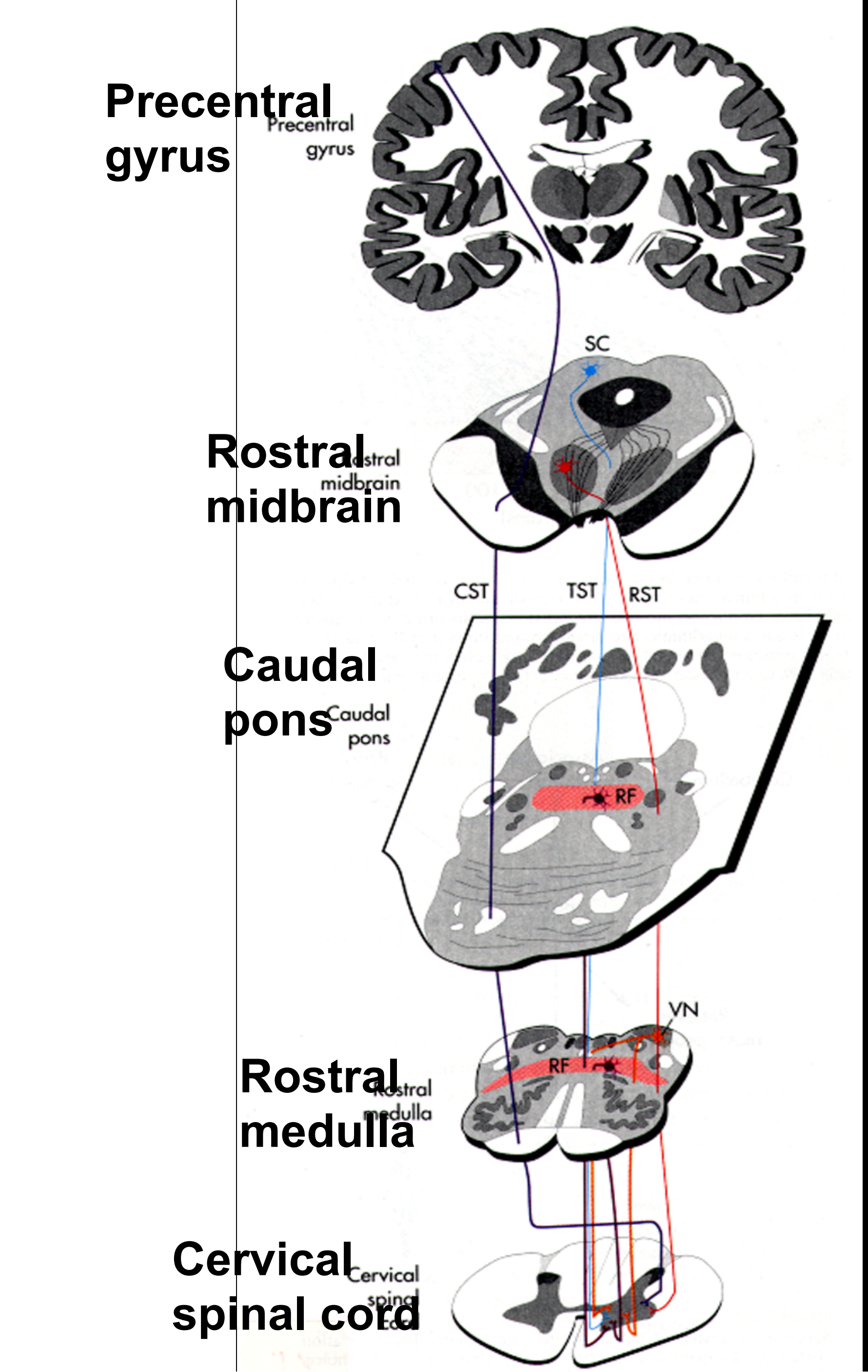
Alpha motor neuron



Clinically, often called Lower Motor Neurons

Descending Spinal Pathways

Upper Motor Neurons



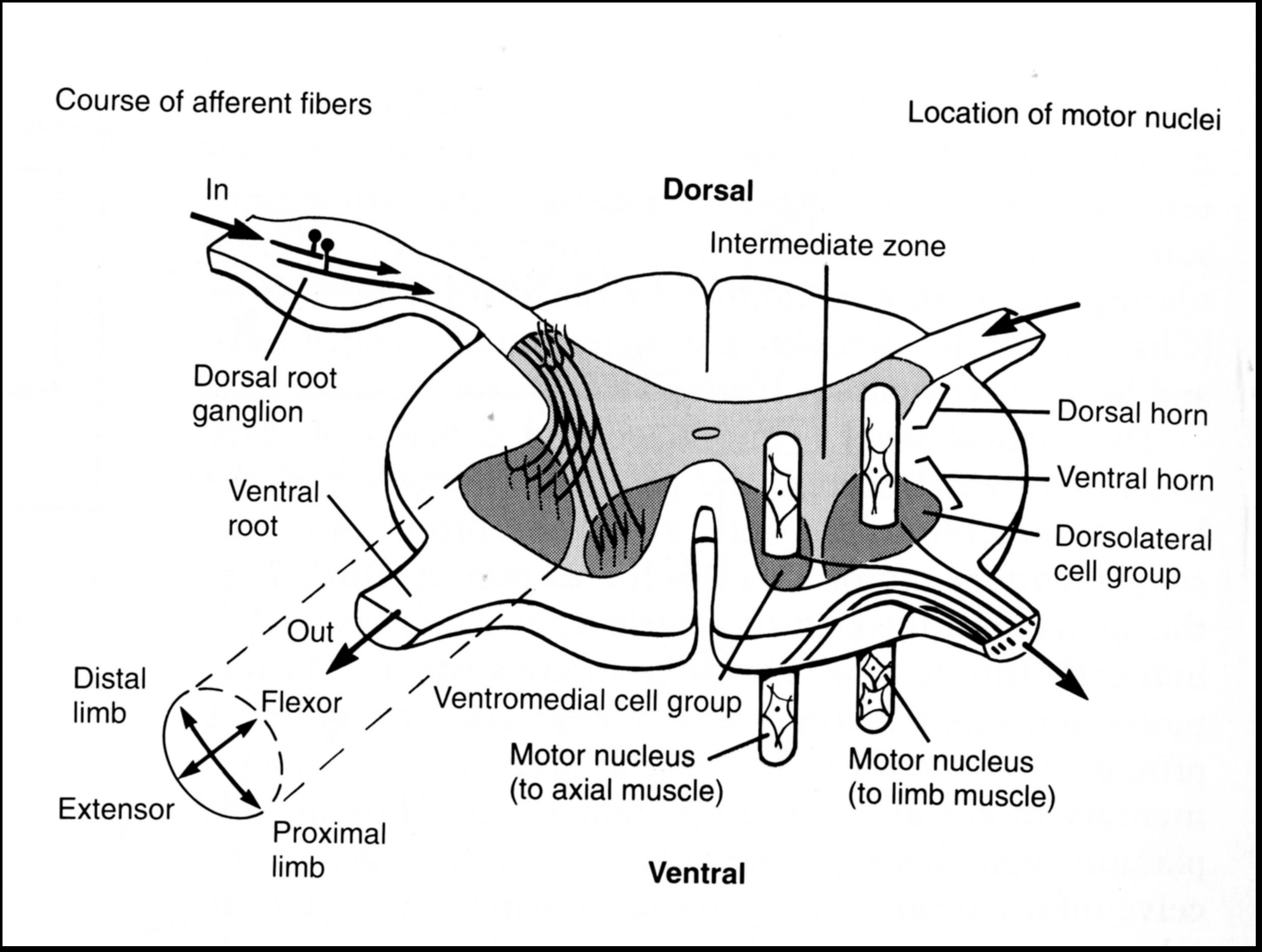
Anatomy and Physiology of Descending Spinal Pathways

Brain structures influence spinal motor neurons and spinal circuits through descending pathways

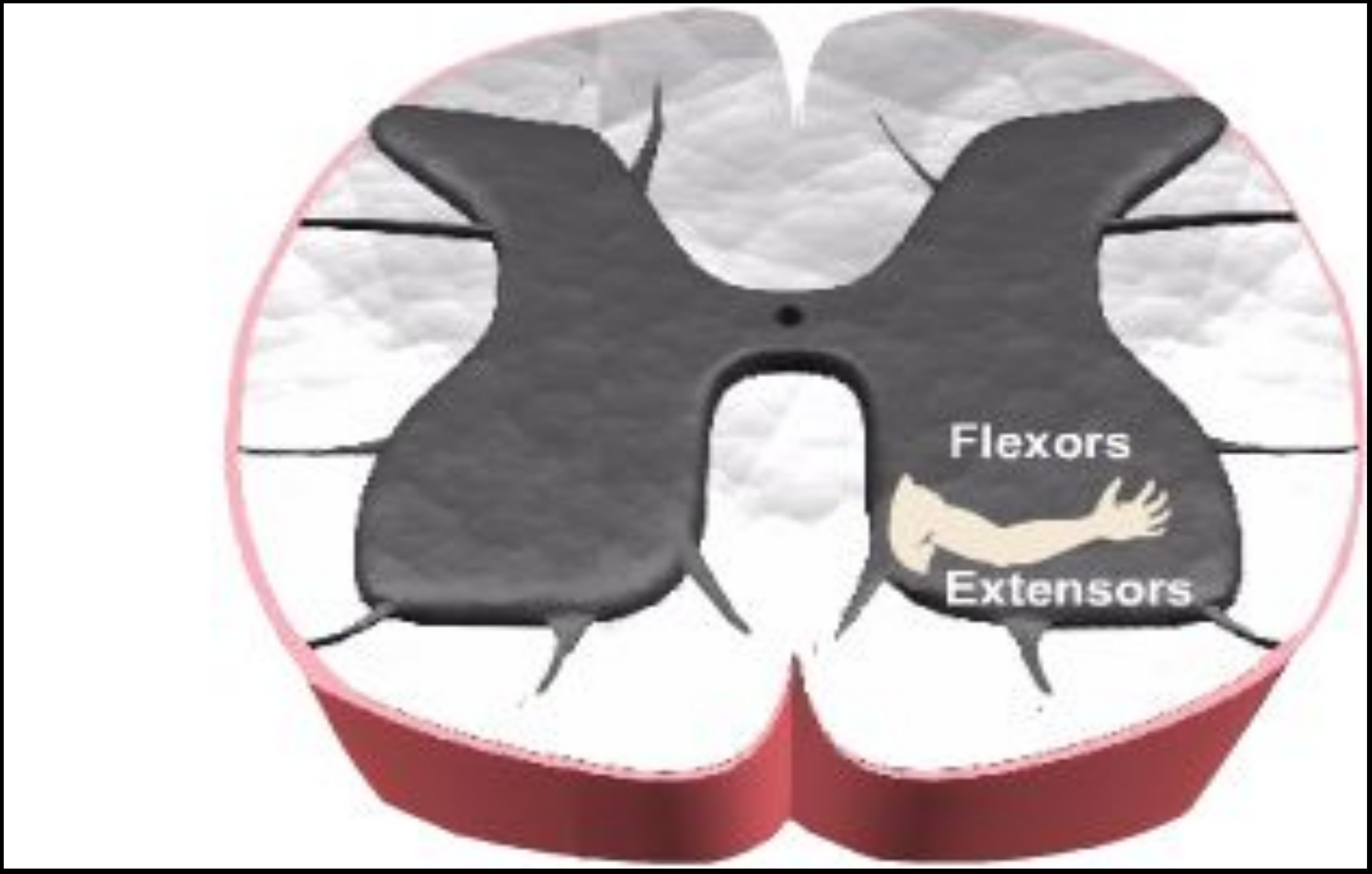
Flexor-extensor rule

Proximal-distal rule

Organization of spinal tracts



Flexor-Extensor Rule and Proximal-Distal Rule



Two Groups of Descending Pathways

Lateral pathways

control proximal and distal muscles

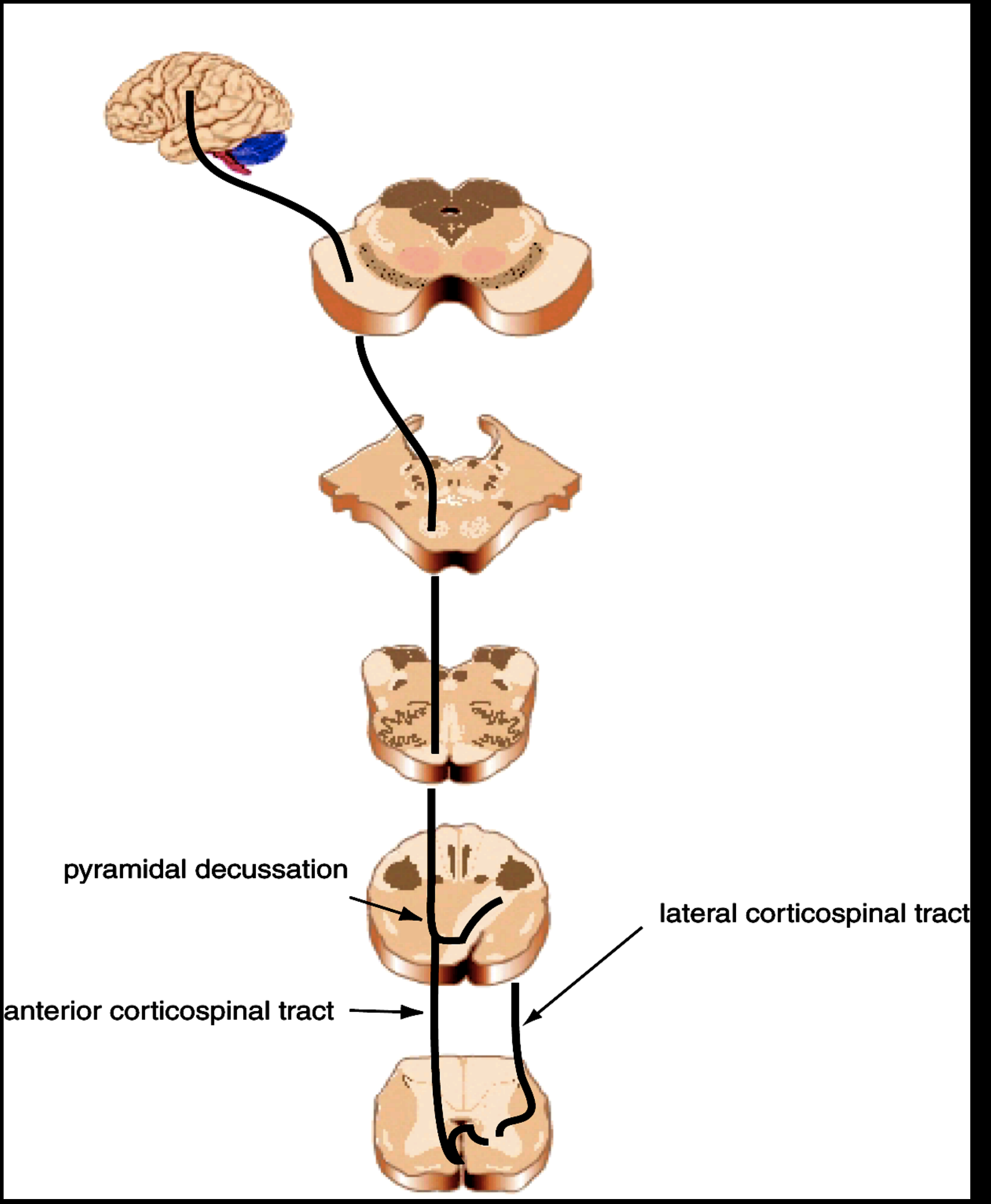
Lateral corticospinal
Rubrospinal

Medial pathways

control axial muscles

Vestibulospinal
Reticulospinal
Tectospinal
Anterior corticospinal

Corticospinal Tracts



Corticospinal tracts

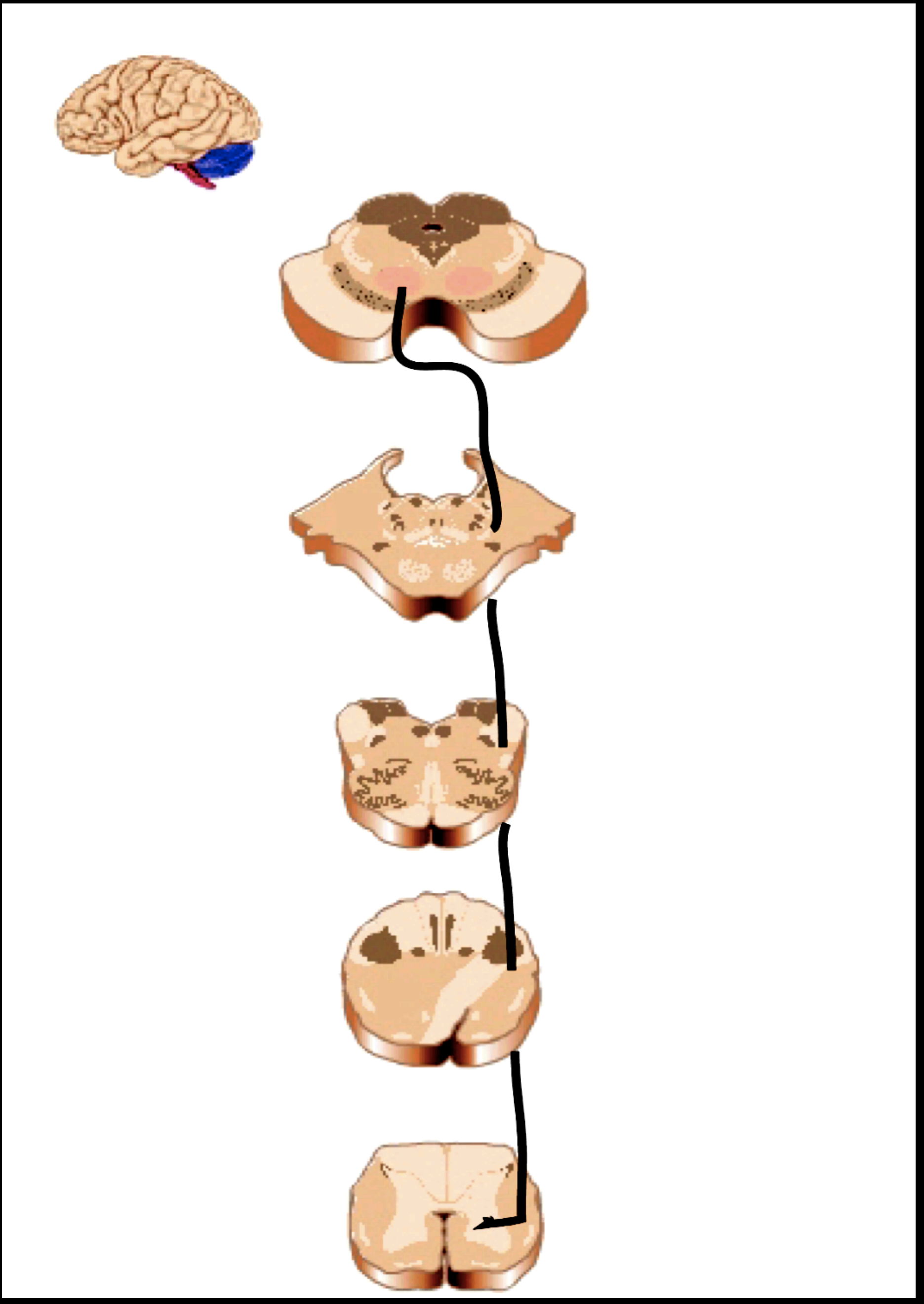
Control of distal musculature, esp. fine control of extremities

Control of axial muscles

Corticospinal and corticobulbar tracts constitute the major *voluntary* drive to the brain stem and spinal motor systems

Lesions produce initial paralysis, with eventual recovery of function (except fine control of distal musculature)

Rubrospinal Tract



Rubrospinal tract

Alternate route to corticospinal tract

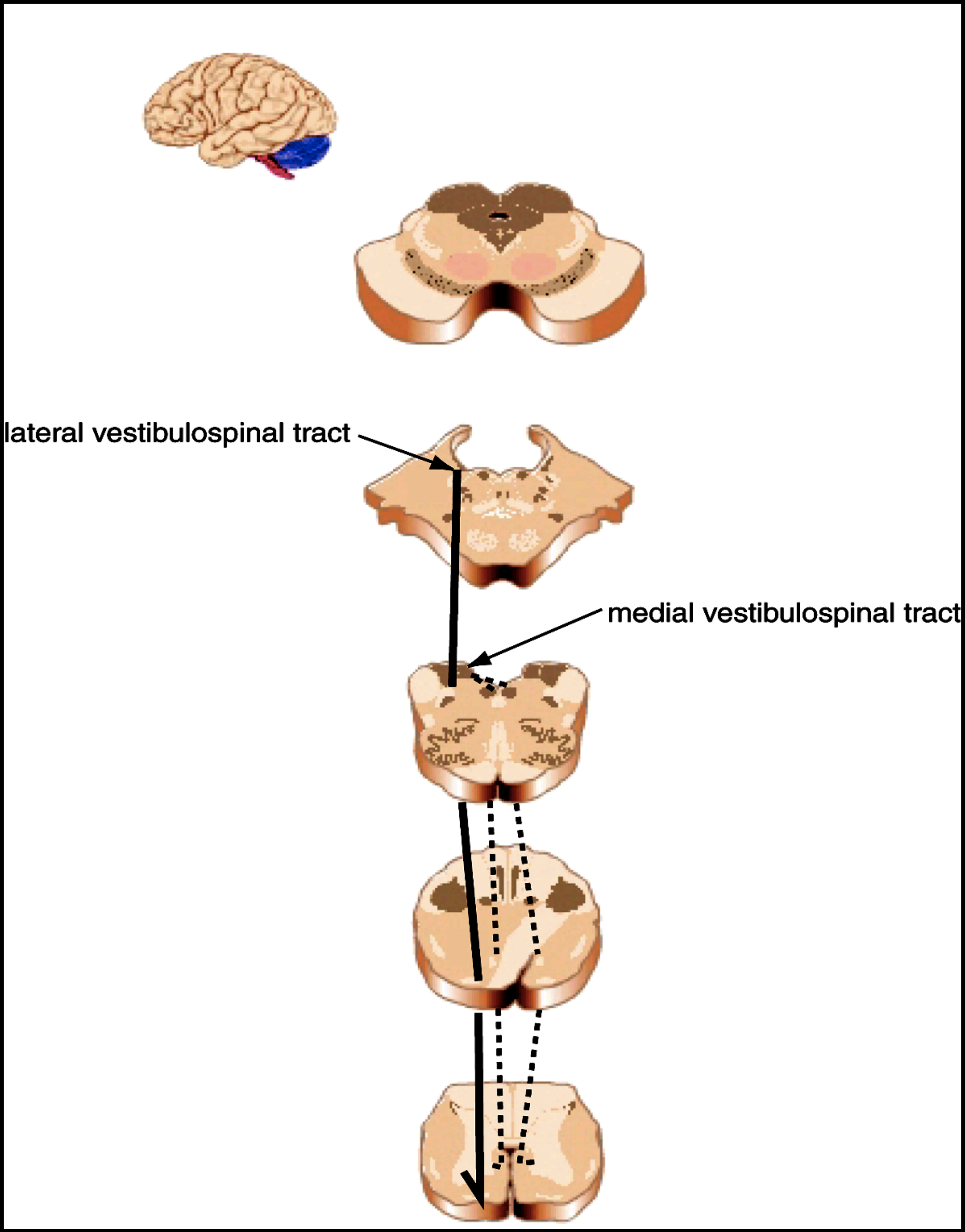
Receives input from cerebellum and cerebral cortex

Encodes movement *velocity*

Excitation of flexors and inhibition of extensors

Relatively small in humans

Vestibulospinal Tracts



Vestibulospinal tracts

Mediate postural adjustments and head movements

Control balance

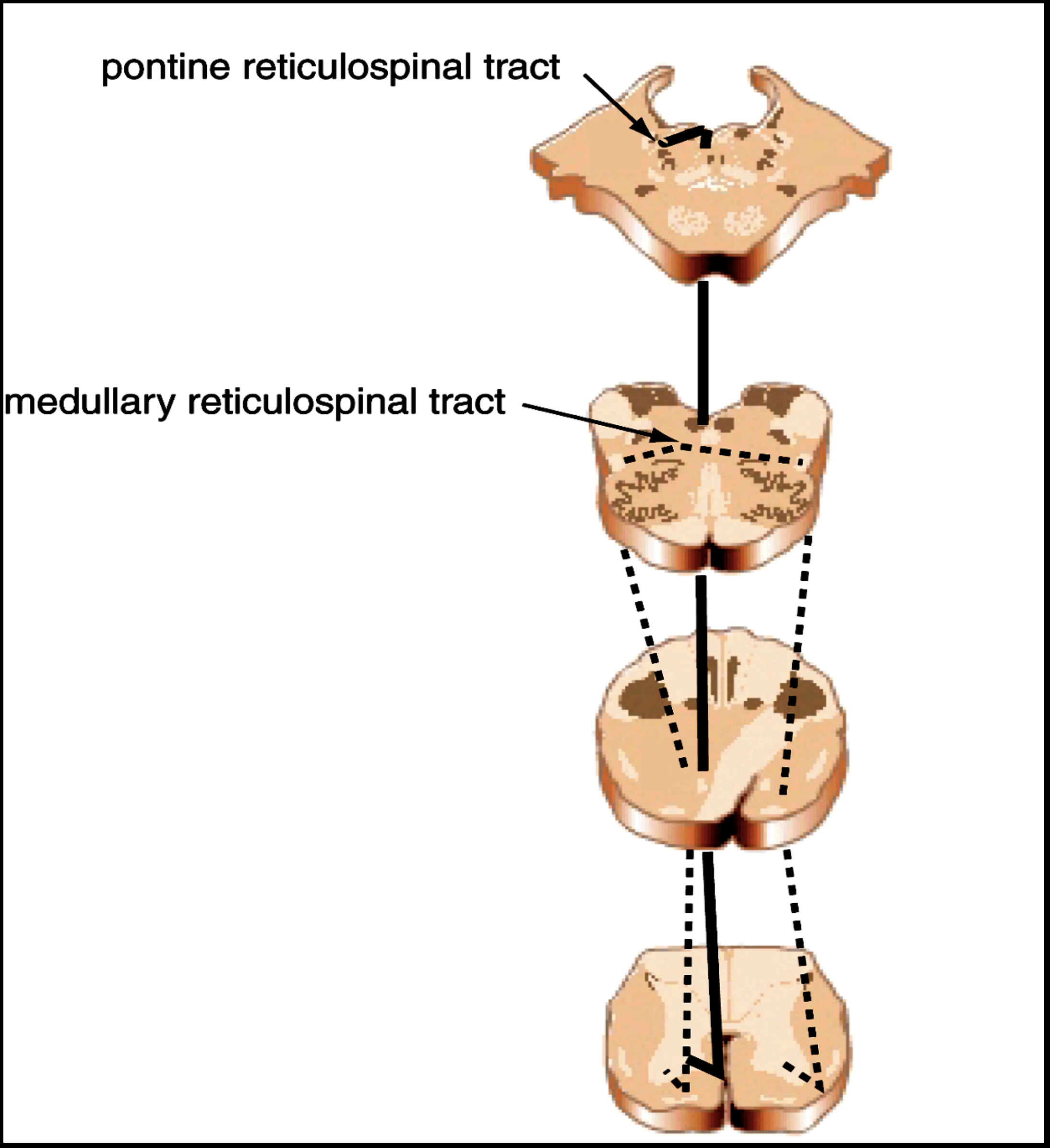
Lateral vestibulospinal tract

- Excites antigravity muscles
- Controls postural changes to compensate for tilts and movements of body

Medial vestibulospinal tract

- Innervates neck muscles to stabilize head position
- Coordinates head and eye movements

Reticulospinal Tracts



Reticulospinal tracts

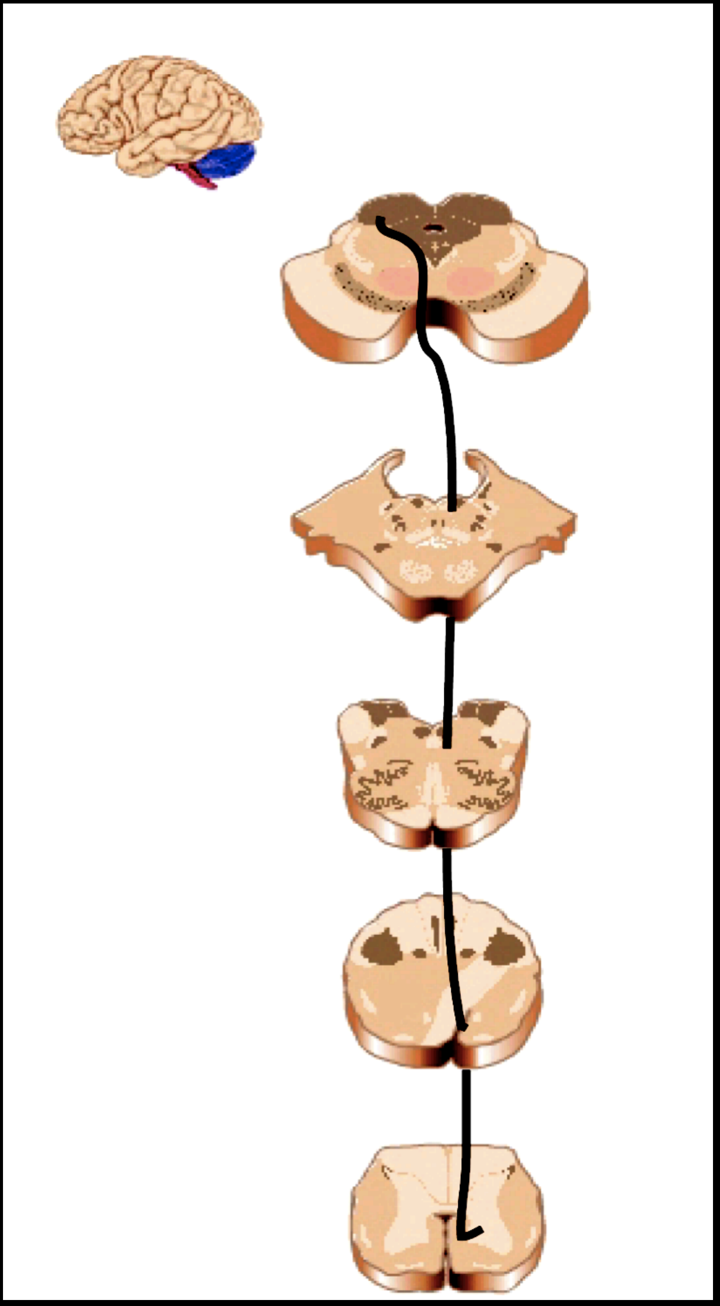
Major alternate route (to the corticospinal tract) to spinal motor neurons

Regulate sensitivity to flexor reflexes, such that only noxious stimuli elicit them

Reticular formation contains circuitry for complex movements, including complex postures, orienting, and stretching

Integration of sensory input to guide motor output

Tectospinal Tract



Tectospinal tract

Originates in Superior Colliculus

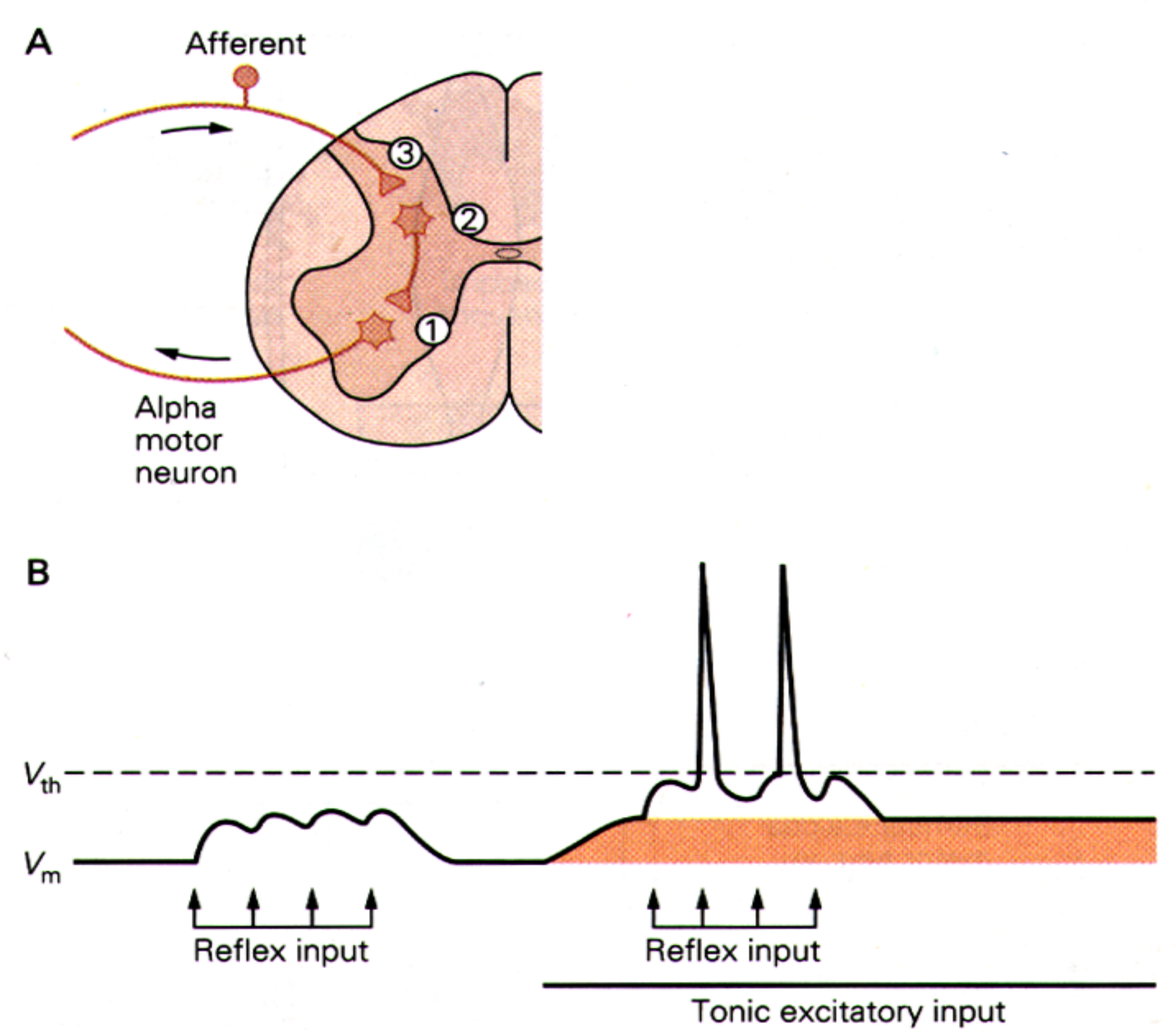
Innervates neck and proximal muscles

Presumably involved in reflex orienting to visual stimuli

Relatively minor in humans

Influence of descending pathways on spinal mechanisms

- voluntary movement
- reflex modulation



From K. Pearson & J. Gordon (2000), in *Principles of Neural Science, 4th Edition* (Kandel, Schwartz, & Jessel, Eds.)

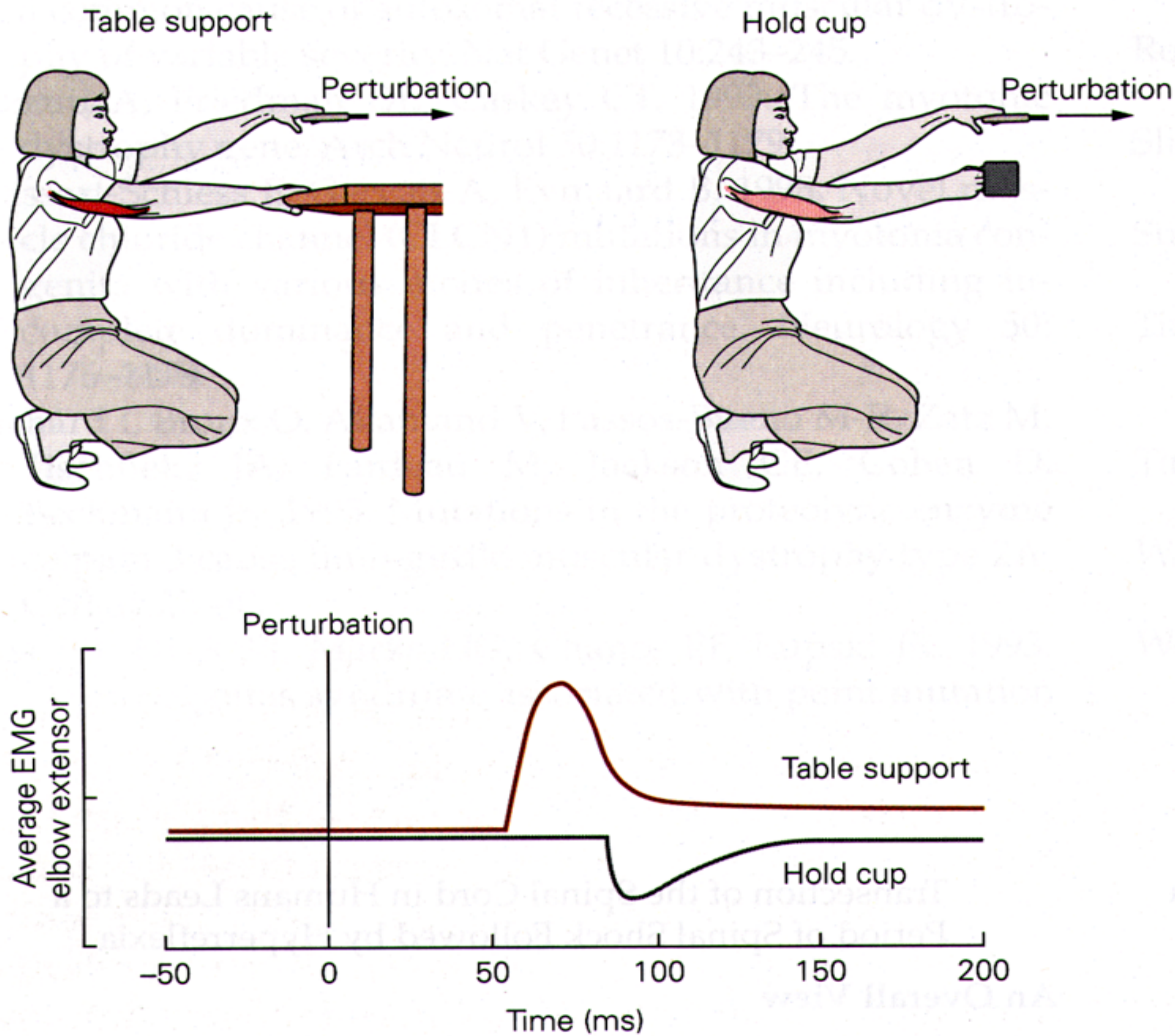
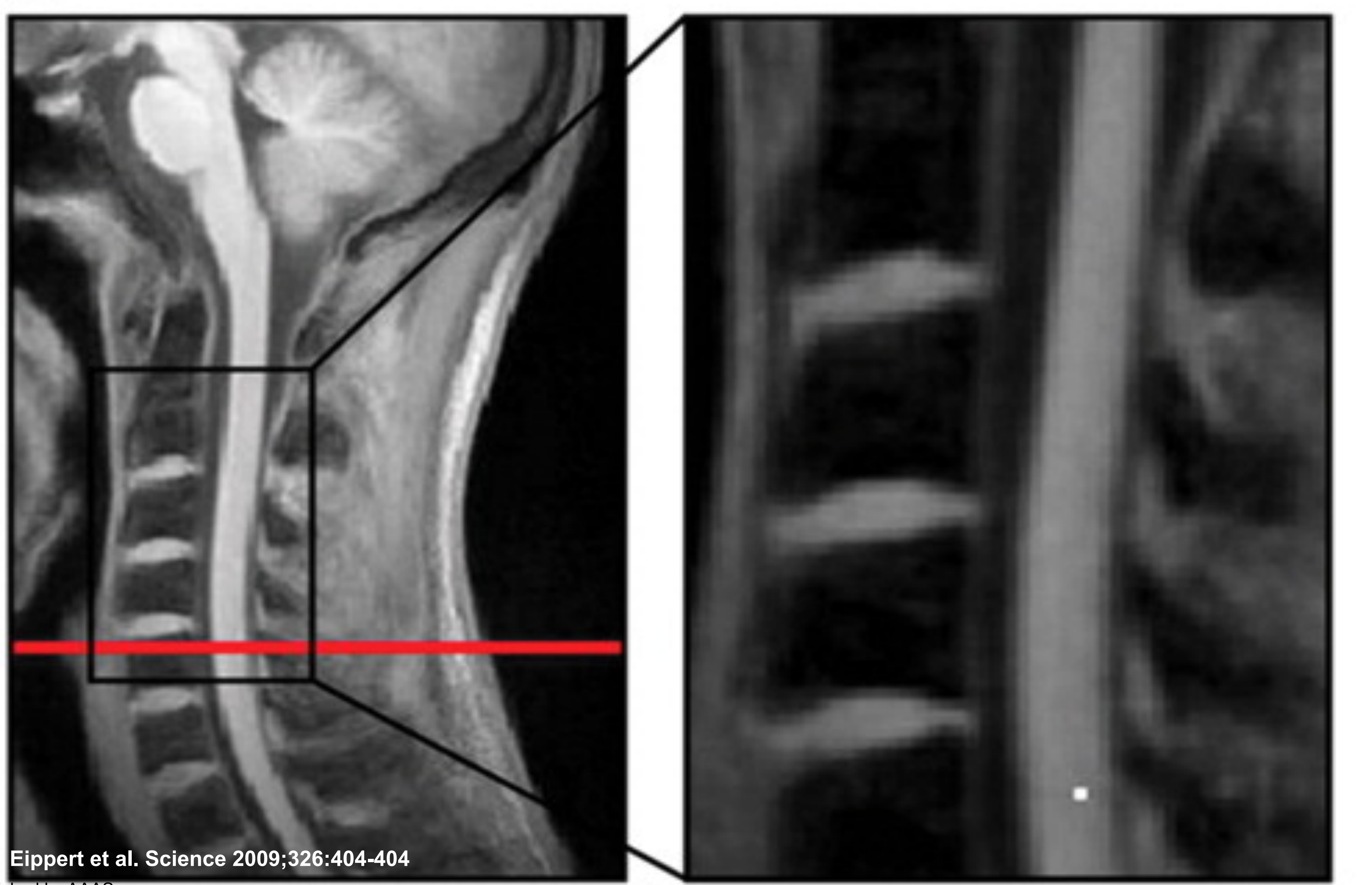


Table support
Perturbation
Hold cup
Perturbation
Perturbation
Average EMG elbow extensor
Table support
Hold cup
–50
0
50
100
150
200
Time (ms)

Influence of descending pathways on spinal mechanisms

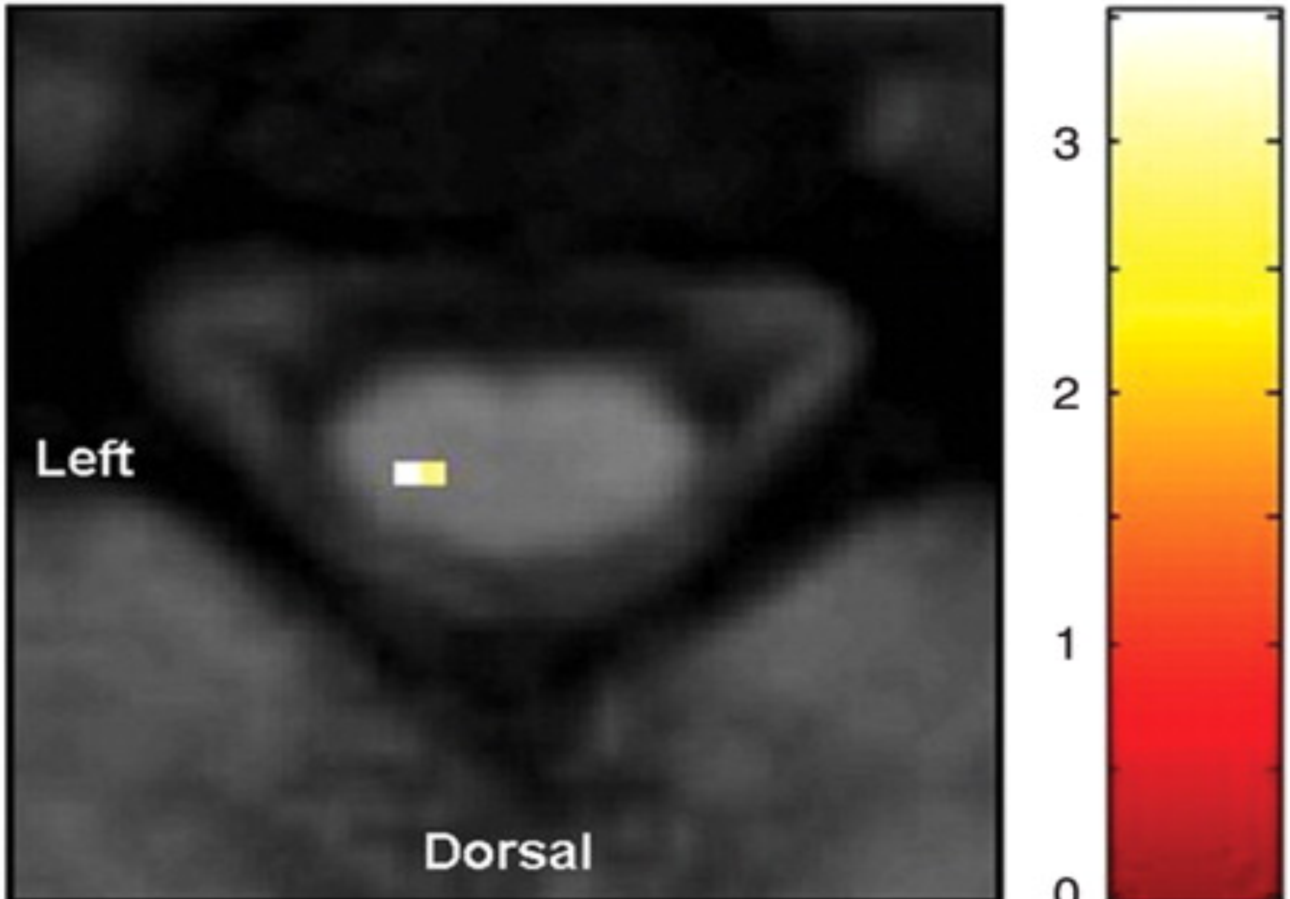
- voluntary movement
- reflex modulation
- gamma bias

  alpha-gamma coactivation

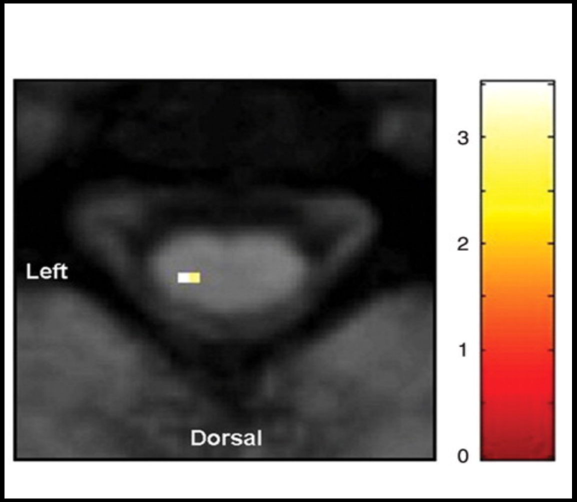


F Eippert et al. Science 2009;326:404-404

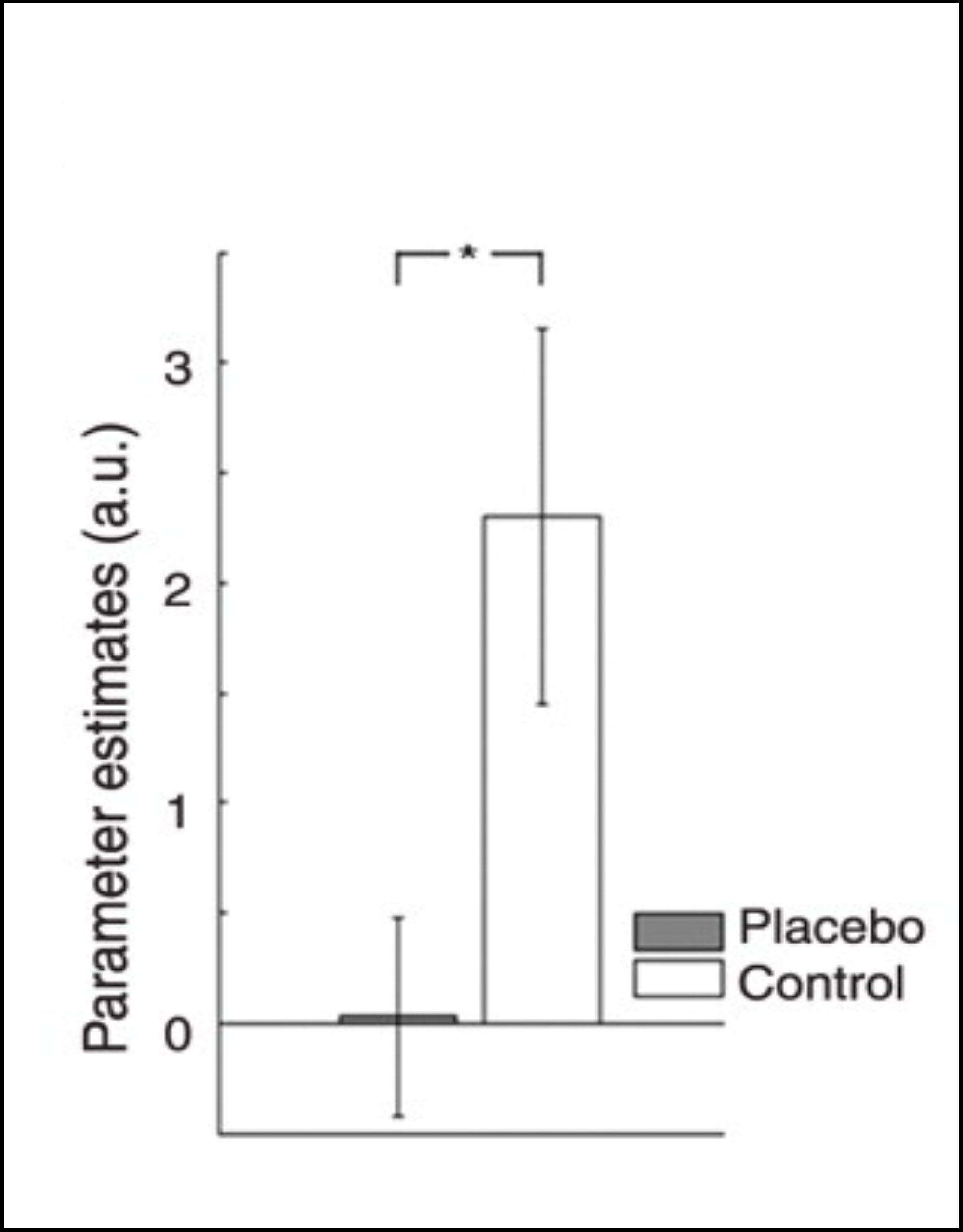
shed by AAAS



F Eippert et al. Science 2009;326:404-404



3
2
1
0
Left
Dorsal



*
Parameter estimates (a.u.)
3
2
1
0
Placebo
Control