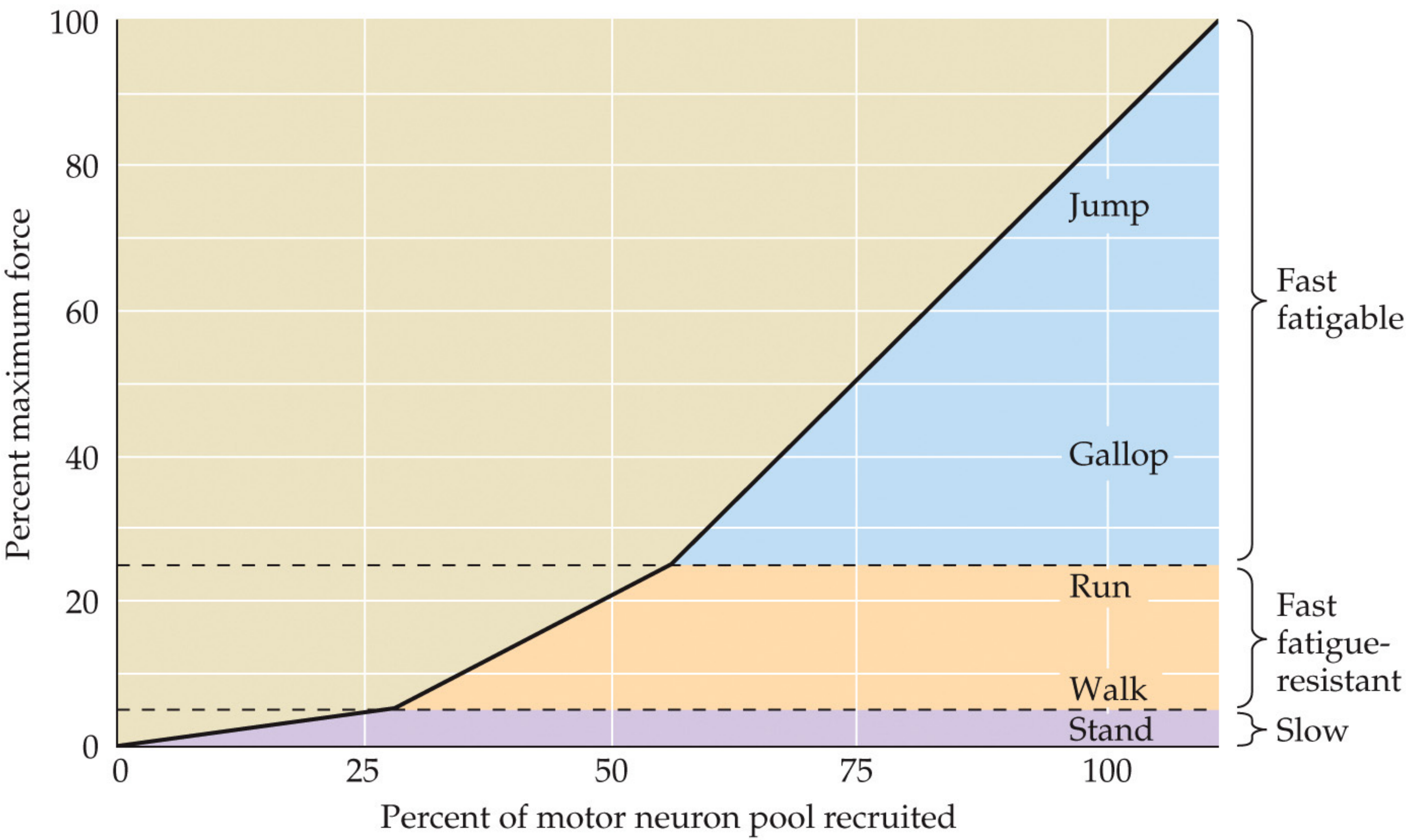
BMD ENG 301
Quantitative Systems Physiology
(Nervous System)

Overview of the Motor System (Part 2)
Start of spinal reflexes

Professor Malcolm MacIver

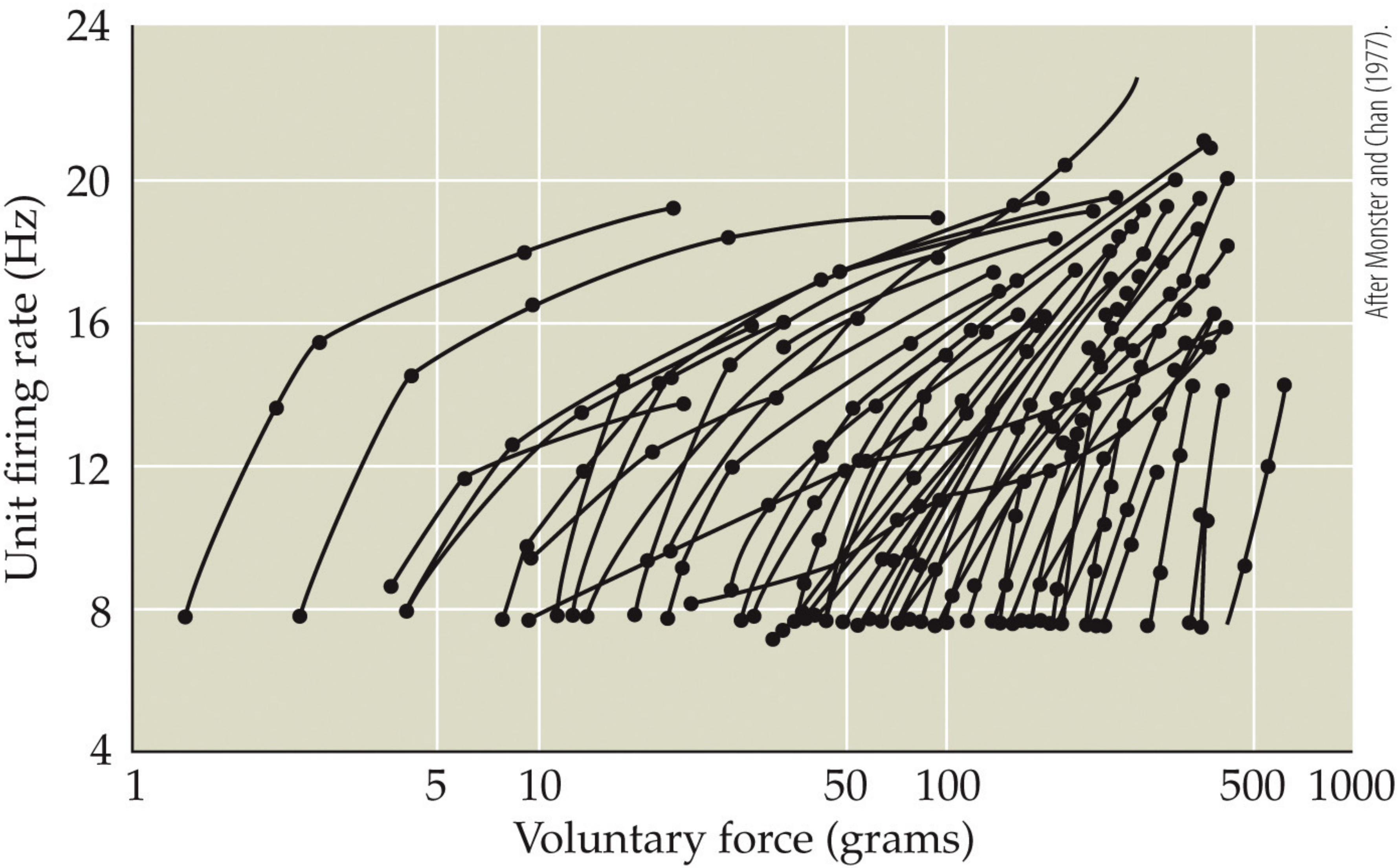
FIGURE 16.7 Motor neuron recruitment in the cat medial gastrocnemius muscle under different behavioral conditions



After Walmsley et al. (1978) *J. Neurophys.* 41: 1203–1216.

***NEUROSCIENCE 6e*, Figure 16.7**

FIGURE 16.9 The number of active motor units and their rate of firing both increase with voluntary force



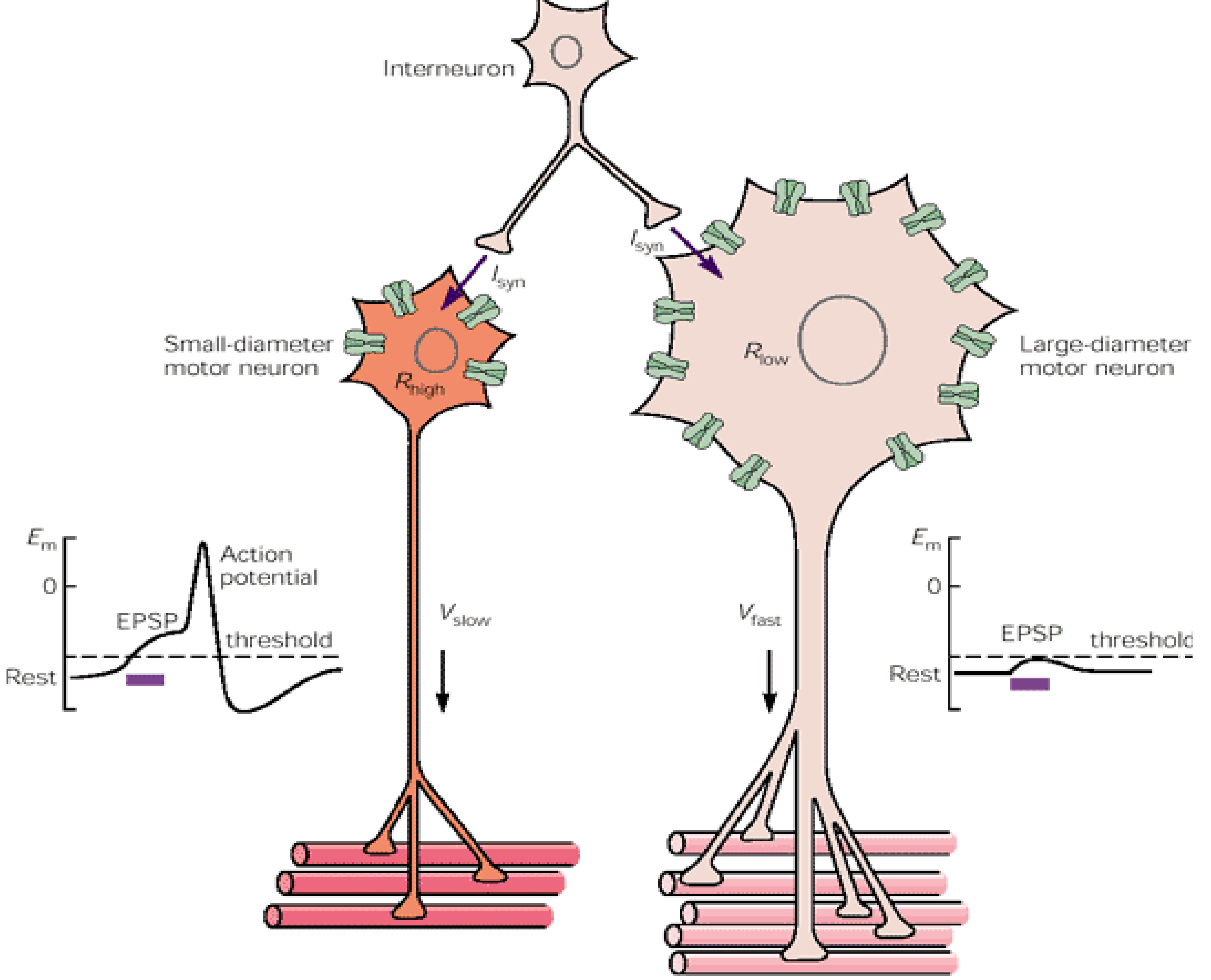
NEUROSCIENCE 6e, Figure 16.9

Features of α motor neurons

	That innervate small motor units		That innervate large motor units
Axonal diameter	Smaller	C	Larger
Input resistance	Larger	O	Smaller
Excitability	Greater	N	Lower
EPSP amplitude	Larger	T	Smaller
Duration of after-hyperpolarization	Longer	I N	Shorter
	-Easily depolarized -Slow rate of firing -Control slow muscle fibers needed for posture	U U M	-Difficult to depolarize -Fast rate of firing -Control fibers that produce max force used for jumping

Increase motor unit size, alpha motor neuron exhibits:

Increased	Decreased
Cell body size	Input resistance
Dendritic Complexity	Excitability
Short-term EPSP potentiation with repeated activation	Ia EPSP amplitude
Axonal diameter (i.e. faster conduction)	PSP decay constant
Number of axonal branches (i.e., more muscle fibers innervated)	Duration of after-hyperpolarization



Interneuron
I_{syn}
I_{syn}
Small-diameter motor neuron
R_{high}
R_{low}
Large-diameter motor neuron
E_m
0
Action potential
EPSP
threshold
Rest
V_{slow}
V_{fast}
E_m
0
EPSP
threshold
Rest

Motor System Plasticity

Nervous system is extremely plastic

- Growth and development
- Injury
- Training

Upper motor centers vs. motor unit plasticity

Aids in understanding of motor neuron and muscle physiology

Great implications in training and rehabilitation

Motor system plasticity

Modification of strength and endurance of motor behavior through experience

- Depends partly on changes in motor unit phenotype
- But MAINLY on changes in supraspinal motor centers

- Nervous system is extremely plastic
  - Growth and development
  - Injury
  - Training
- Upper motor centers vs. motor unit plasticity
- Aids in understanding of motor neuron and muscle physiology
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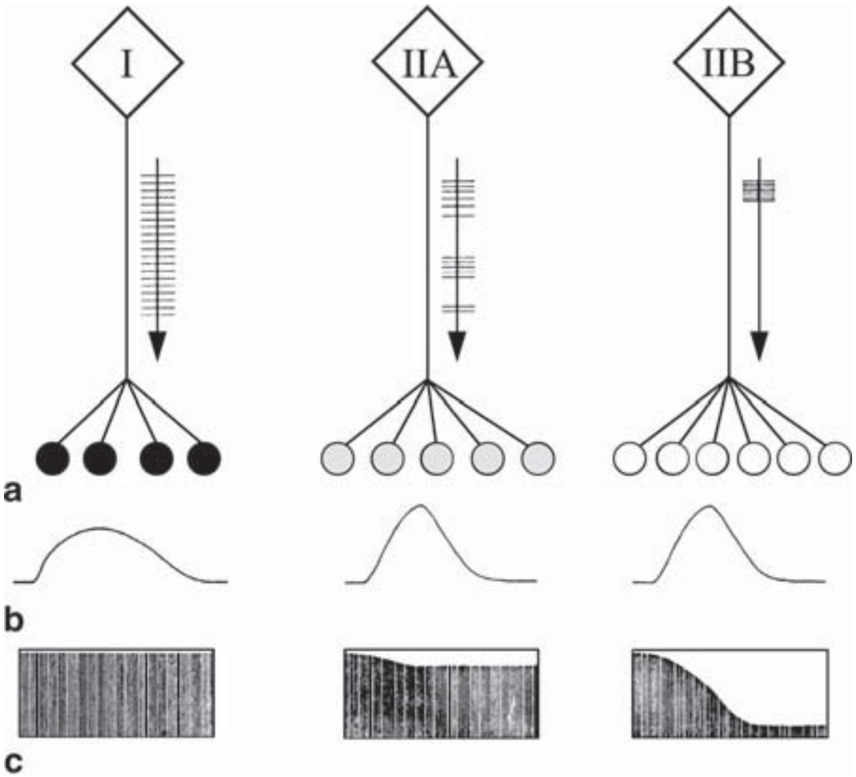
Types of Motor Unit

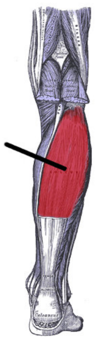


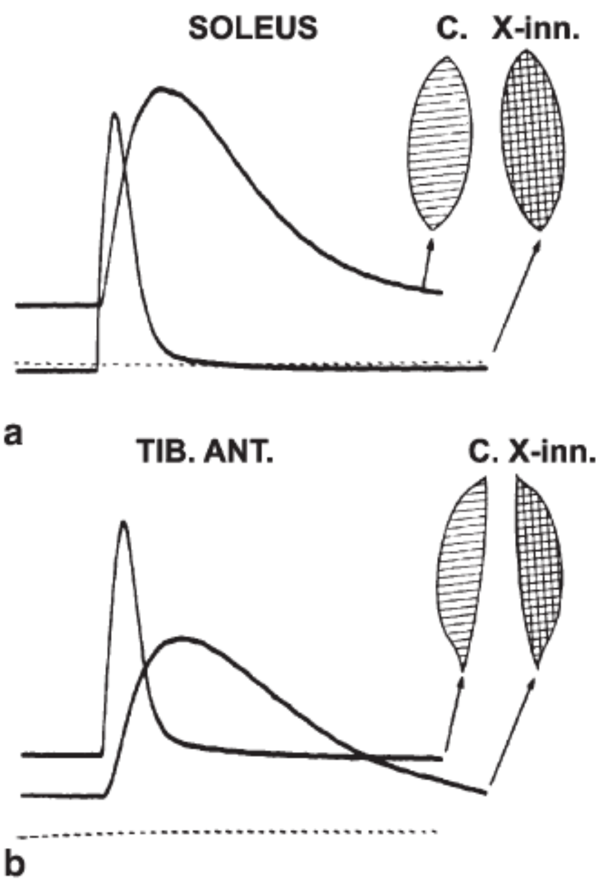
- 3 types of alpha motor neuron
  - Excitability
  - Discharge frequency
- 3 types of muscle fibers
  - Contraction speed
  - Fatigability

Motor unit plasticity

- Motor units are important site of plasticity in the nervous system
- Results of studies with cross-innervation and electrical stimulation show properties of motor neurons determine muscle fiber behavior
- Motor unit behavior is modified by training
- Important implications for exercise and rehabilitation programs

Soleus





Tibius
anterior

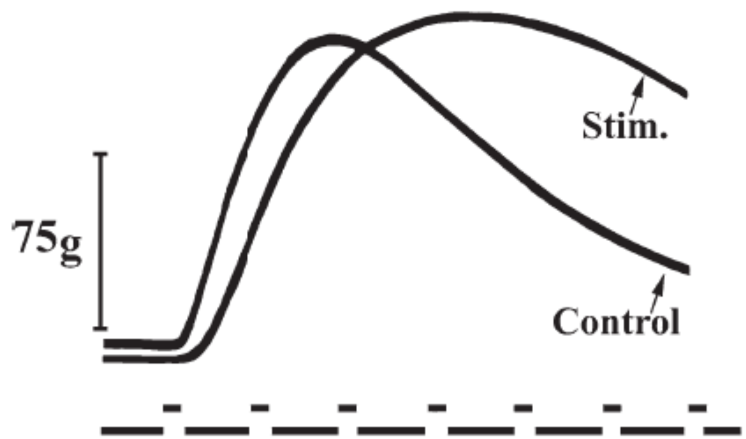
- Soleus- slow muscle with constant, low frequency innervation
- TA- fast muscle with intermittent, high frequency innervation
- With cross-innervation:
  - Soleus become fast
  - TA became slow
- Shows motorneuron innervation determines muscle fiber phenotype

Electrical Stimulation

Electrical stimulation can change behavior of muscle fiber

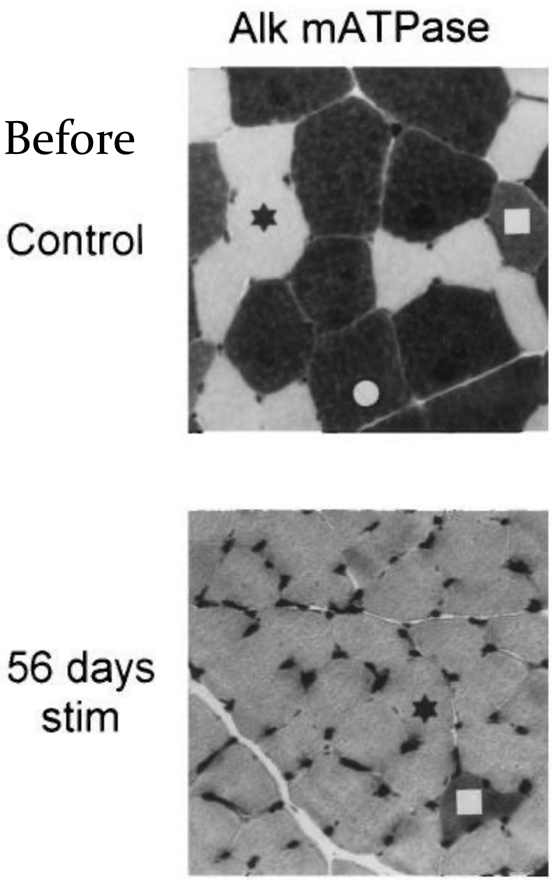
- Frequency dependence

Electrical stimulation at low frequencies can prevent slow muscle from becoming fast muscle with disuse



Fast muscle stimulated at 10 Hz

Cross-innervation experiments



Fast fatigable fiber
Fast fatigue resistant fiber
Slow

Stained muscle for myosin ATPase activity

Before

- Fast fatigable and fast fatigue resistant fibers are darker
- Slow fibers are lighter

After chronic electrical nerve stimulation similar to the innervation that slow fibers receive

- Almost all fibers show phenotype of slow fibers (lighter)

Motor Unit Plasticity

Ability of motor neurons and the muscles they innervate to change physically and functionally

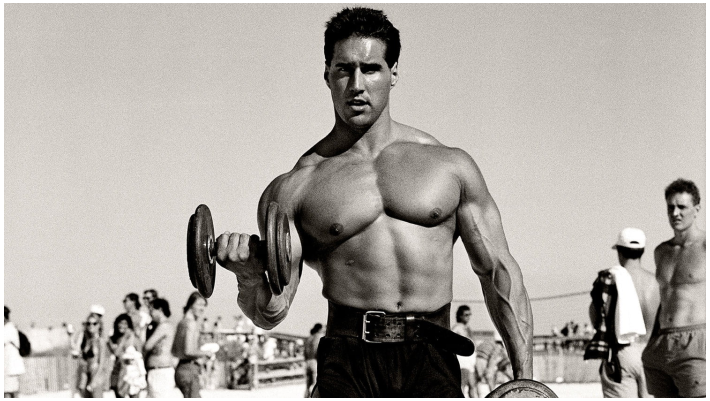
- Acquire new motor skills
- Modify the strength and endurance of motor behavior

In general exercise:

- slows the contractile properties of motor units
- Increases endurance of fibers

The impact of exercise is proportional to the order of recruitment

- Exercise has a greater impact on slow motor units at low exertion levels
- Only has an impact on fast fibers if high intensity exercise is performed



- Most commonly, exercise “slows” contractile properties of motor units while increasing endurance and strength of muscle fibers
- S motor units affected most at low exertion levels
- FR and FF motor units affected only if recruited by higher intensities of exercise

- Appreciable gains shown in non-exercised limb
  - Recruitment and adaptation of central neural circuits that have access to contralateral motor units
- Documented gains in muscle strength with imagined exercise

- Appreciable gains shown in non-exercised limb
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Unilateral and Imagined Exercise

- Appreciable gains shown in non-exercised limb
  - Recruitment and adaptation of central neural circuits that have access to contralateral motor units
- Documented gains in muscle strength with imagined exercise

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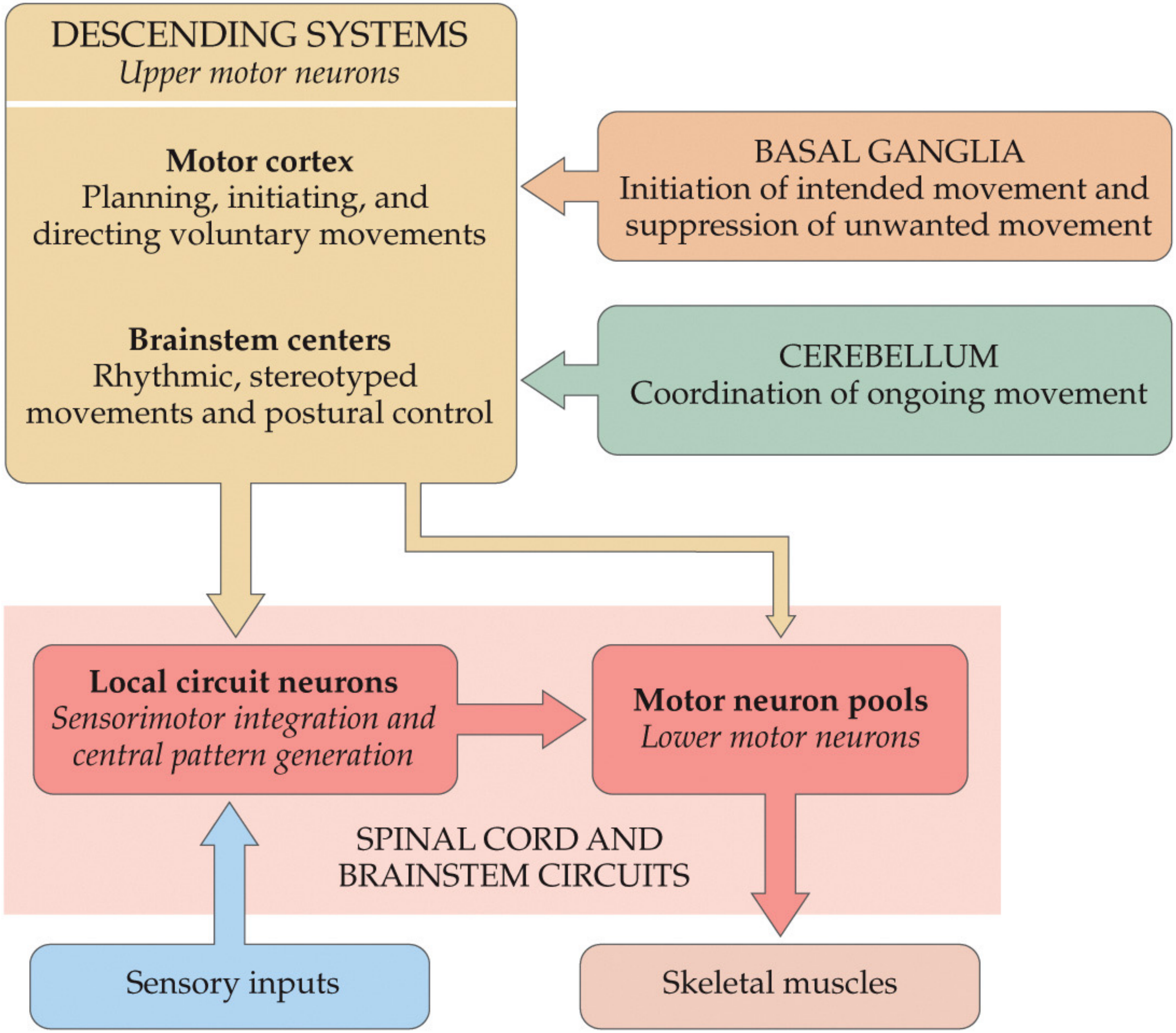
Spinal Reflex Circuits

Malcolm MacIver

Organization of neural structures involved in the control of movement



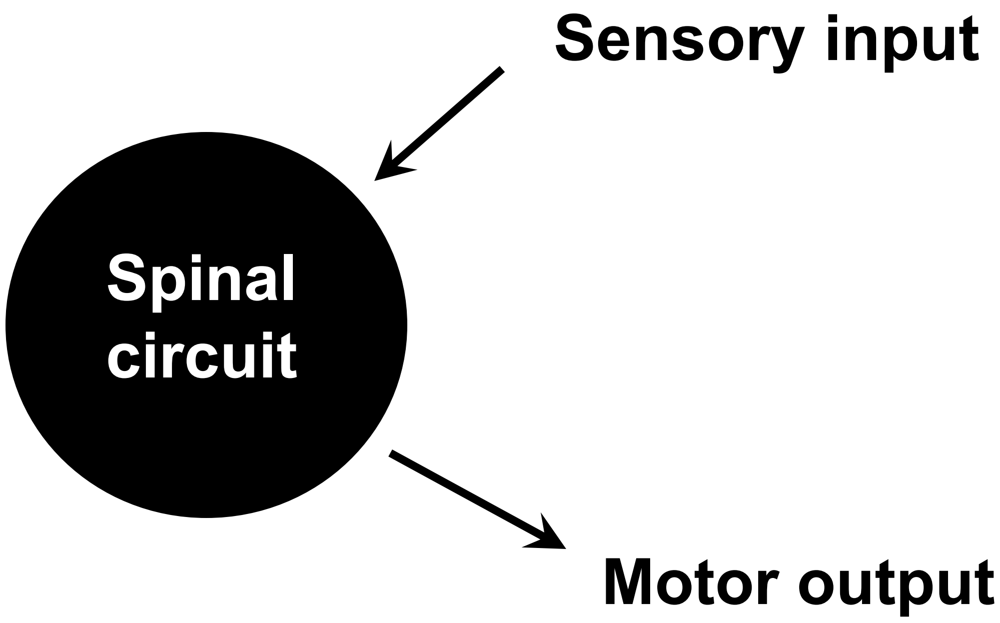
NEUROSCIENCE 6e, Figure 16.1

Reflexes

1. A simple motor action that is stereotypical and repeatable
2. Elicited by a sensory stimulus, the strength of the motor action being graded with the intensity of the stimulus

Dr. Charles Sherrington 1857-1952 (1932 Nobel Prize for discoveries regarding functions of neurons)

- Published “The integrative Action of the Nervous System” in 1906

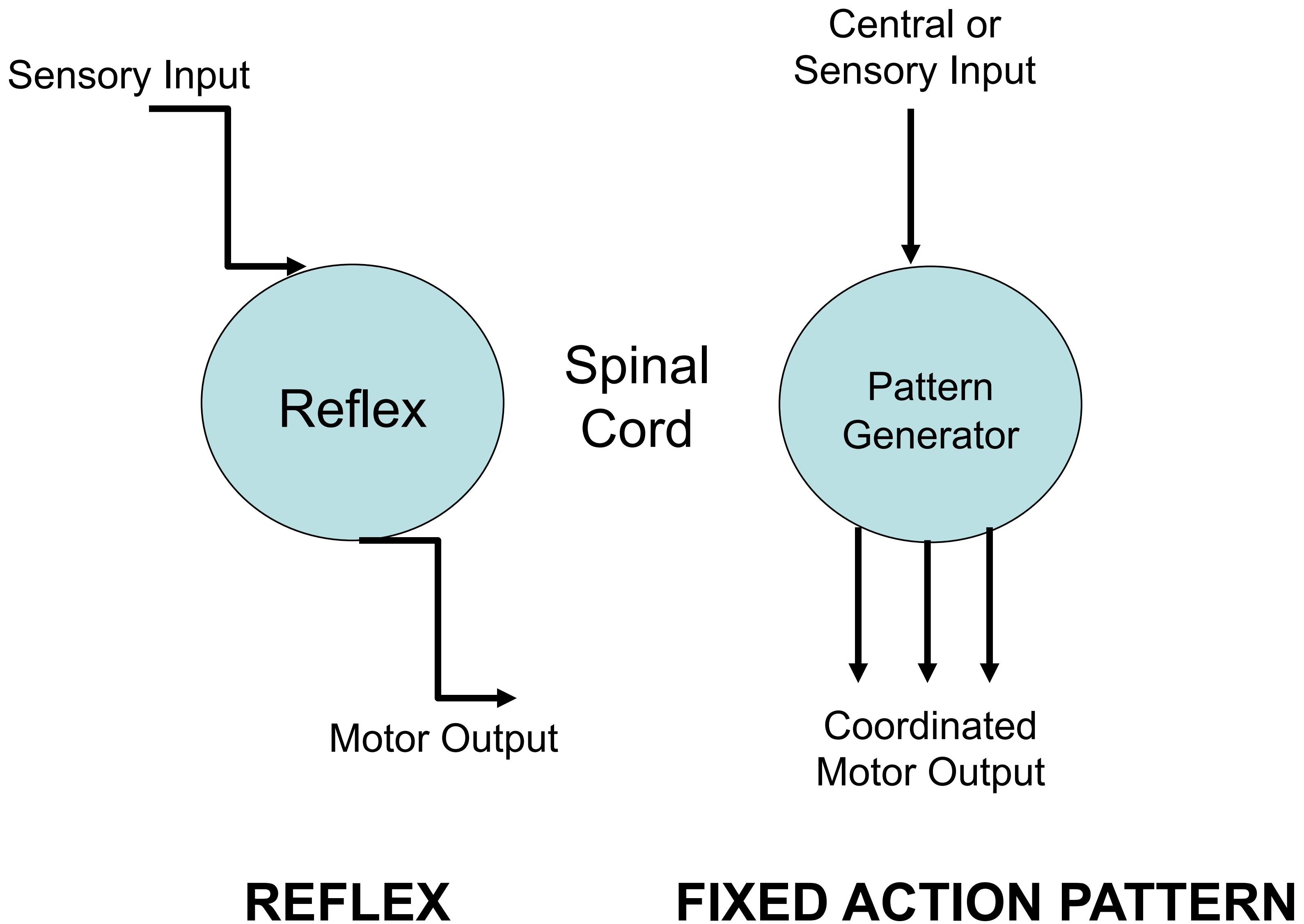

Sensory input
Spinal circuit
Motor output

Benefits of Spinal Circuits

Speed of Signal transmission

If a signal needs to propagate to the brain and back, a typical reaction time is **0.25** seconds, whereas a reflex will typically take closer to **0.15** seconds.

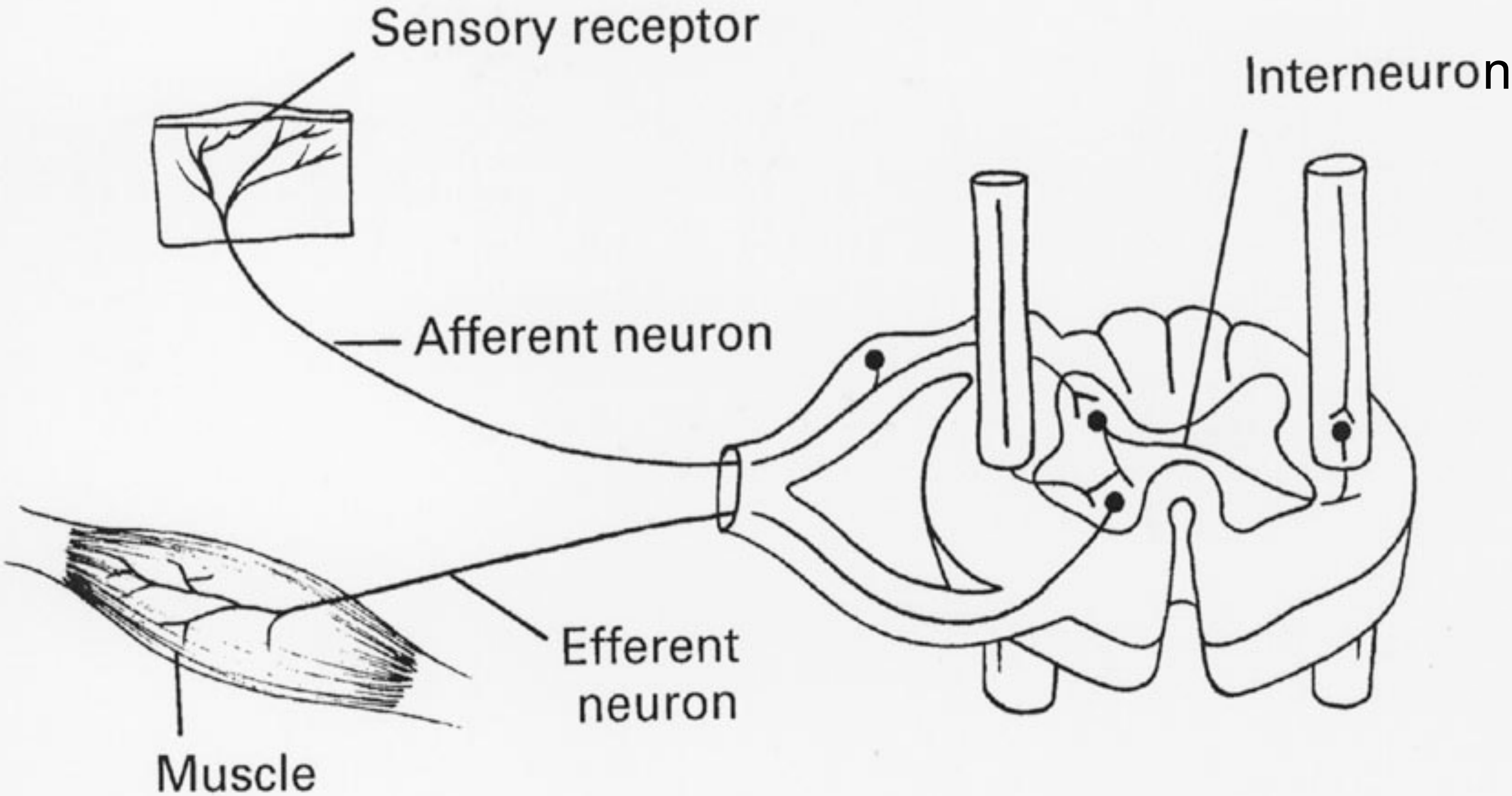
Fixed Action Patterns *versus* Reflexes

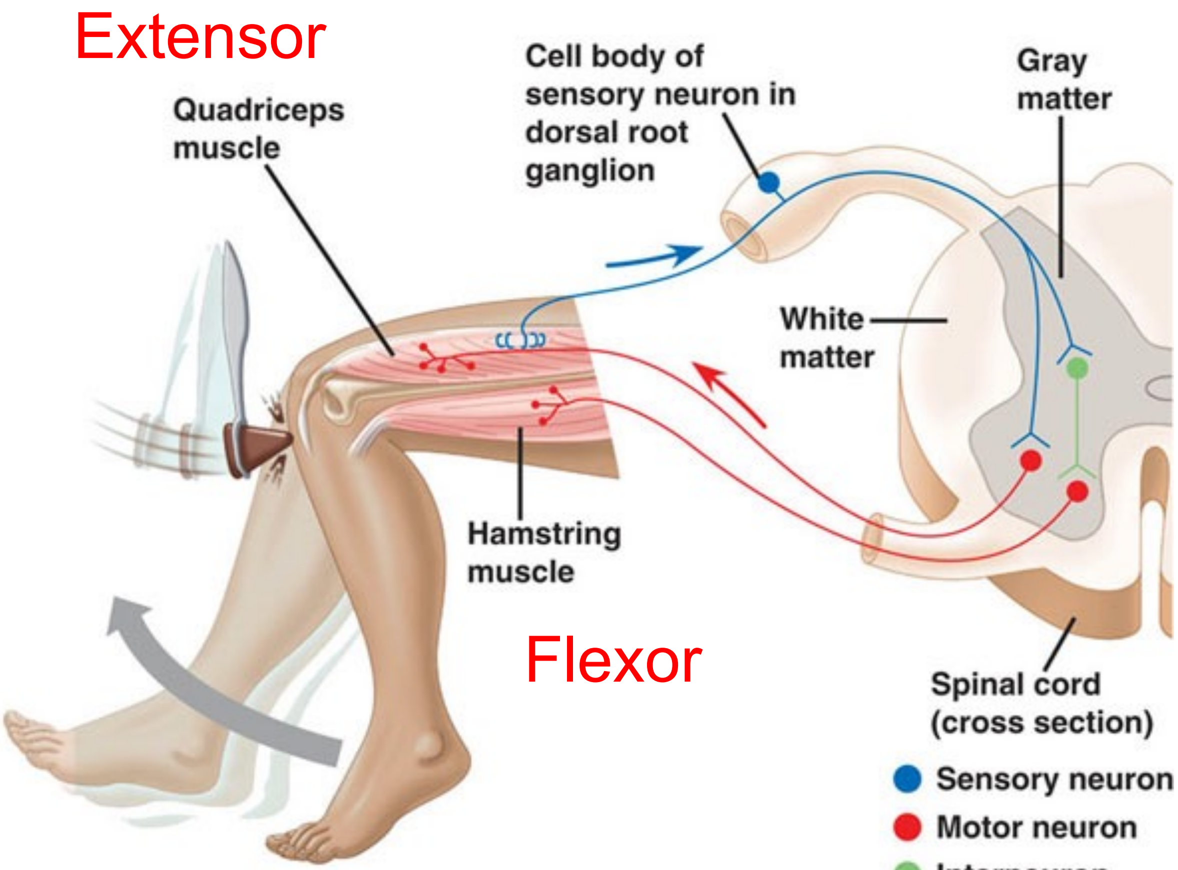


Fixed Action Patterns *versus* Reflexes

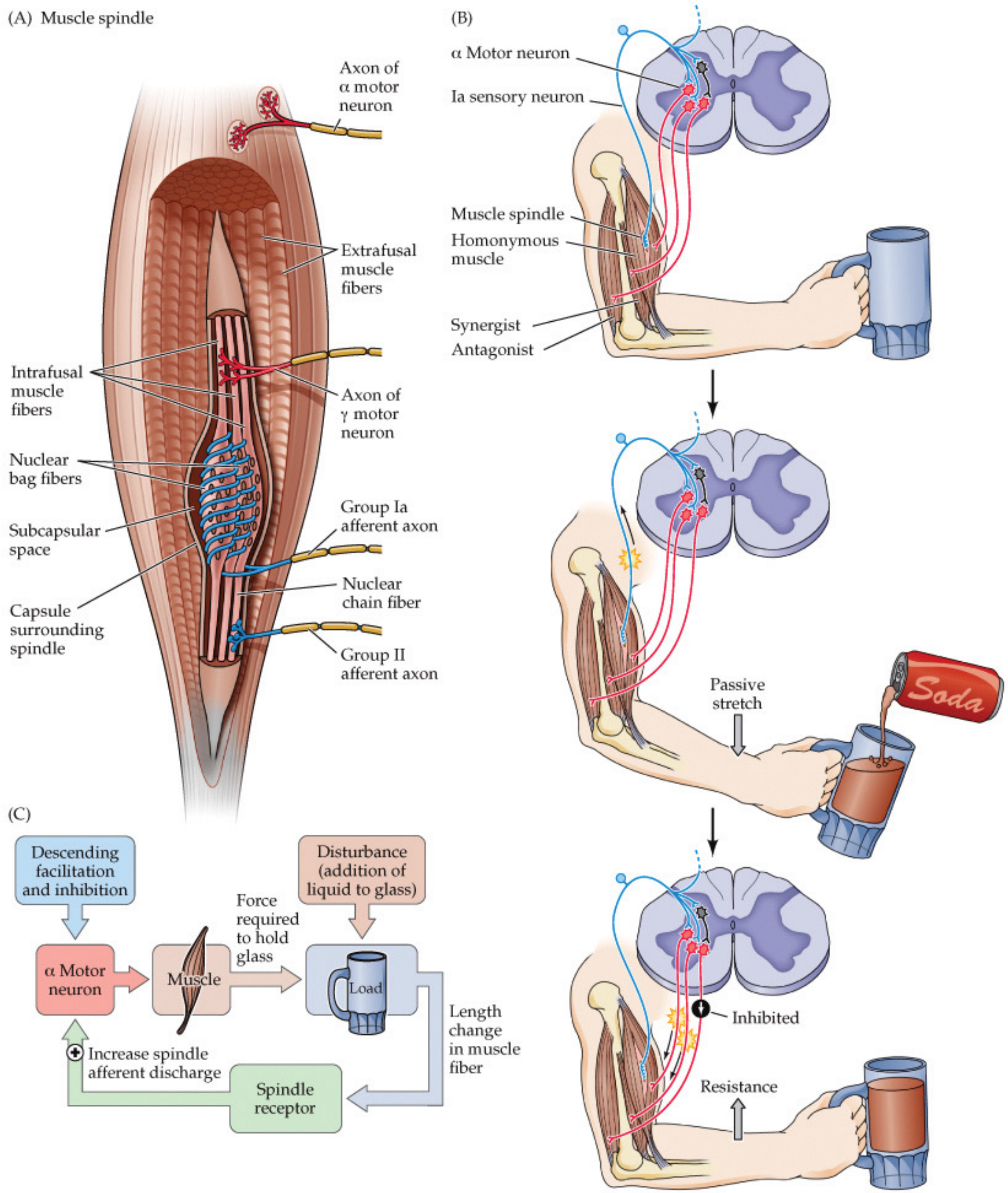
Reflex	Fixed Action Pattern
A simple stereotyped and repeatable motor action	A complex motor act, involving a specific temporal sequence of component motor acts
Elicited by a sensory stimulus. Magnitude of the motor response increases with the strength of the sensory drive.	Generated internally or initiated by a sensory stimulus. The stimulus triggers release of the coordinated motor act. The action may be all-or-none or graded in intensity, and it may be dependent on the type of sensory stimulus or internal state, but it maintains its basic pattern.

Simplest Circuit

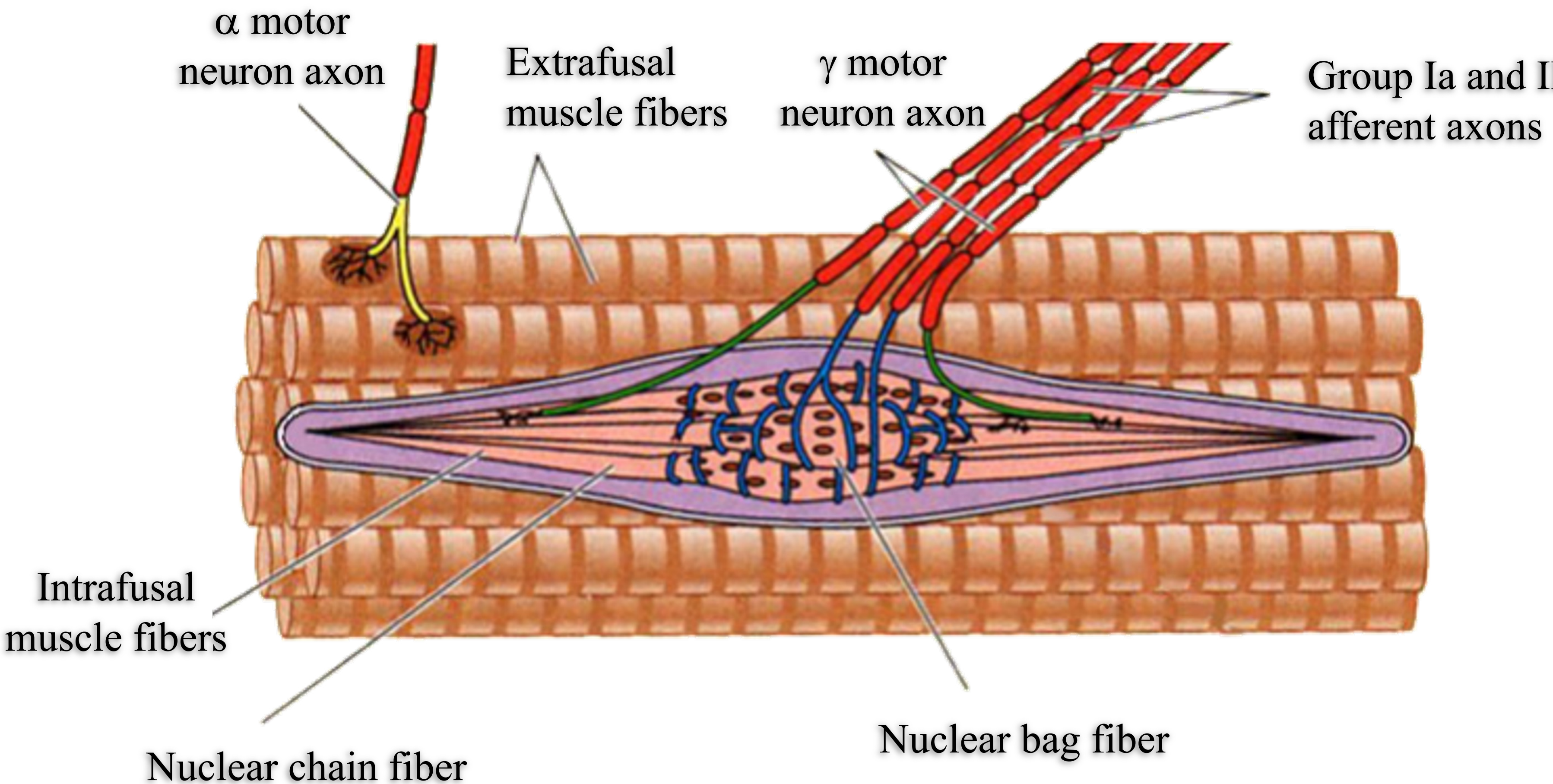



Extensor
Quadriceps muscle
Cell body of sensory neuron in dorsal root ganglion
Gray matter
White matter
Hamstring muscle
Flexor
Spinal cord (cross section)
Sensory neuron
Motor neuron
Interneuron

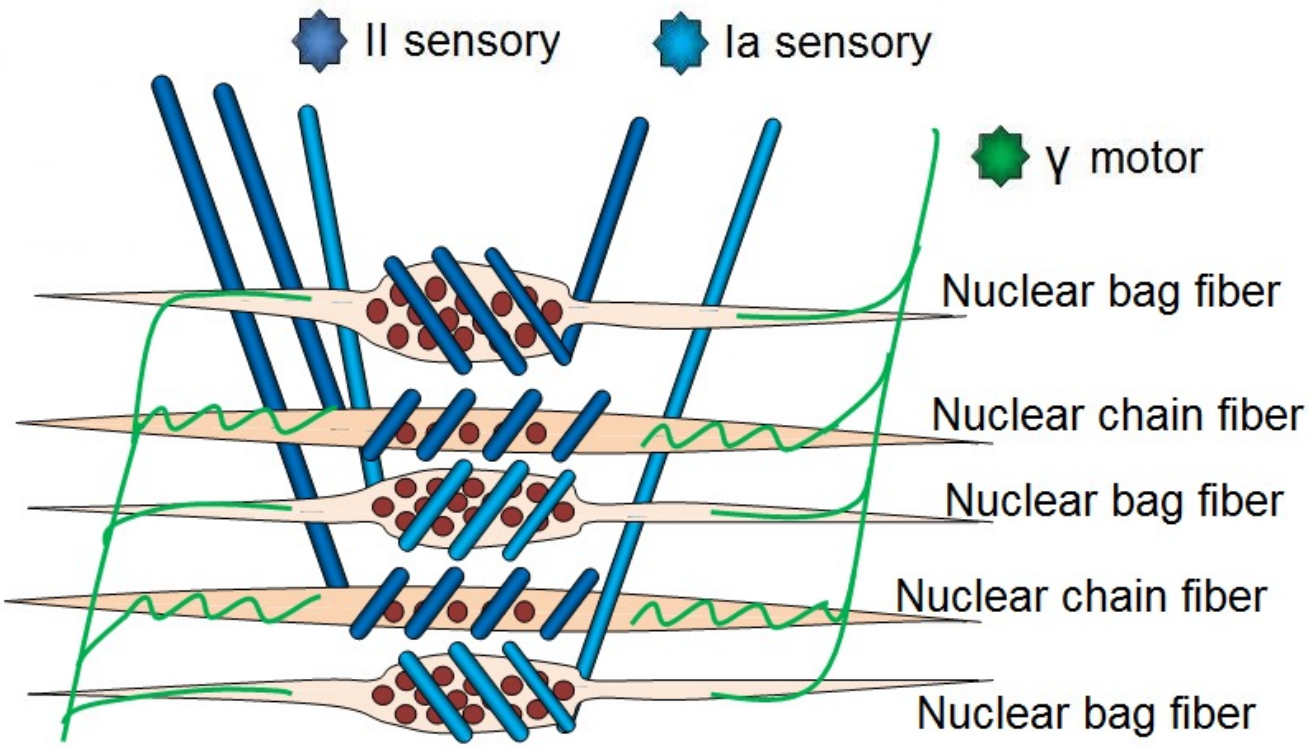
Stretch reflex circuitry



NEUROSCIENCE 6e, Figure 16.10


α motor
neuron axon
Extrafusal
muscle fibers
γ motor
neuron axon
Group Ia and II
afferent axons
Intrafusal
muscle fibers
Nuclear chain fiber
Nuclear bag fiber

- Sensory axons coil around intrafusal fibers
- Stretch in fibers activates mechanically gated ion channels in sensory axons
- Ia sensory around bag fibers
- II sensory around bag and chain

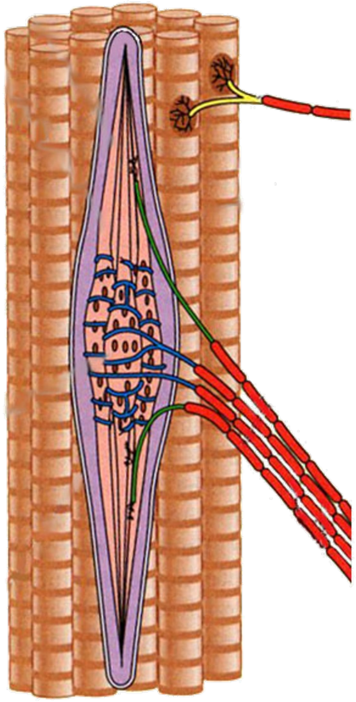


Eight to ten intrafusal fibers

Contained in collagen sheath

Two types of fibers

- Nuclear bag fibers
  - Excite Ia and II sensory afferents
  - Sensitive to dynamic changes (rapidly adapting)
  - Non-contractile
- Nuclear chain fibers
  - Half the size of bag fibers
  - Excite II sensory afferents only
  - Sensitive to static levels of stretch
  - Contractile



Functions

Primary afferents (group Ia)

- Sense changes in muscle length
  - Limb dynamics (velocity and direction)

Secondary afferents (group II)

- Sense sustained muscle stretch
  - Static limb position

Proprioceptor Activity