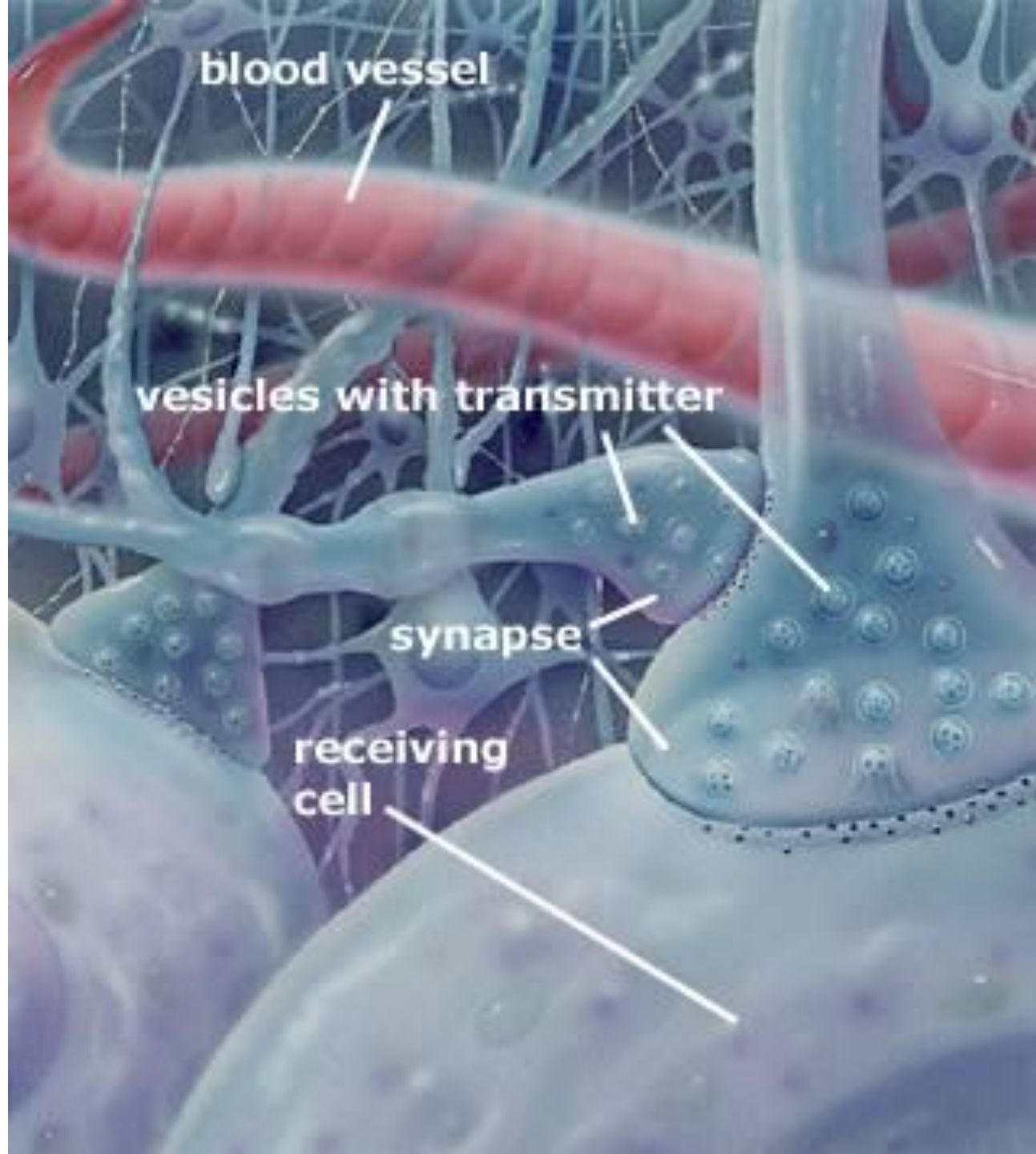


# **CSB 332**

## **Neurobiology of the Synapse**

***Melanie A. Woodin***  
***January 2012***

***Lecture 16***  
***Motor Control***  
***Chpt 24***





- ## Sensory feedback





# Neural organization of motor control is hierarchical

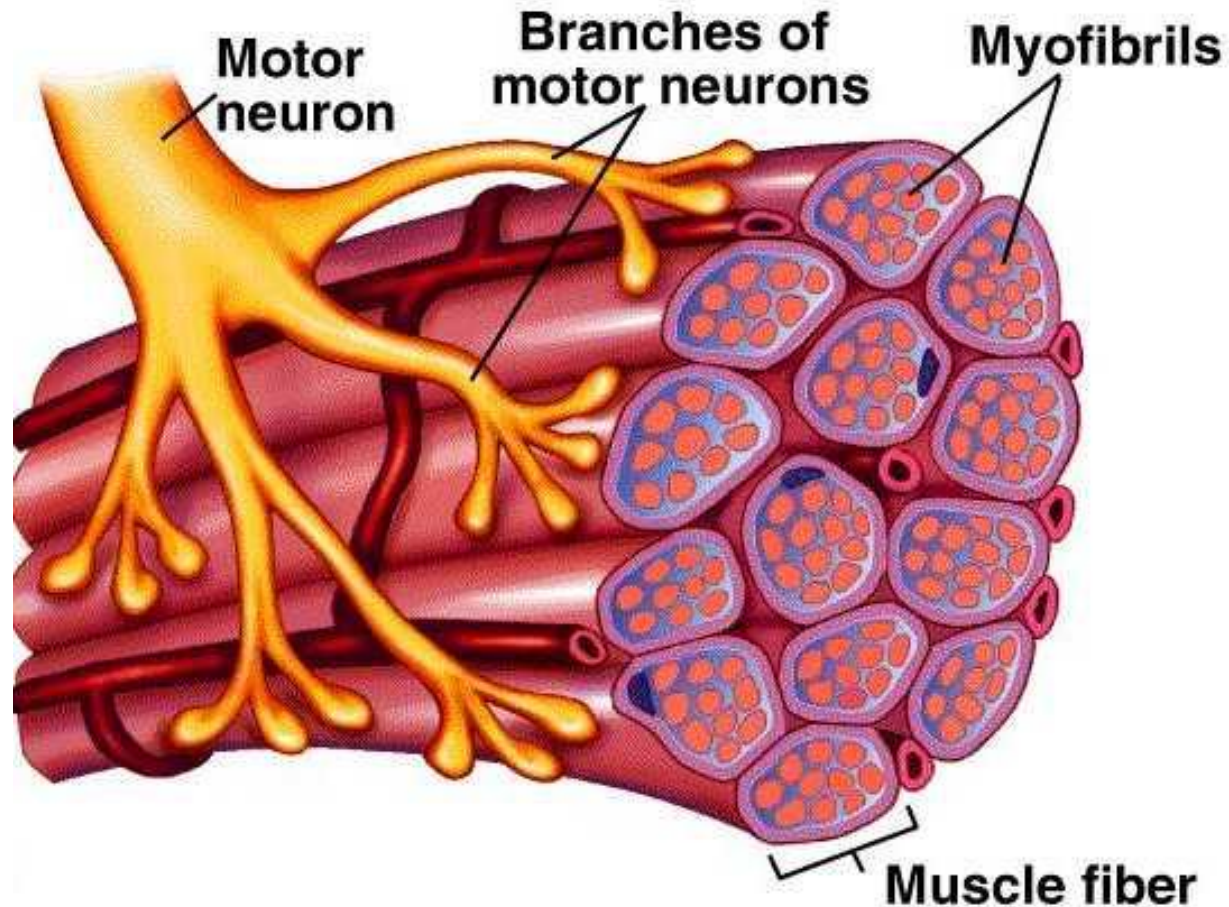
- 1. *Simplest level: sensory neurons synapse with motoneurons in the spinal cord to mediate simple reflexes***
- 2. *Central pattern generators: networks of interneurons in the spinal cord and brainstem coordinating the interplay of multiple motor groups (locomotion, respiration)***
- 3. Motor output that is planned and refined by the motor cortex, basal ganglia and cerebellum**



- Sherrington called the spinal motoneuron the final common path because all the neural influences that concern movement or posture converge upon it
- **$\alpha$  motoneurons** – the major motoneurons of the spinal cord
- **$\gamma$  motoneurons** – are smaller motoneurons that regulate the sensitivity of muscle spindles
- **Motor unit** – a single  $\alpha$  motoneuron and the muscle fibers it innervates
- **Motor pool** – all the motor neurons supplying a particular muscle



# The Motor Unit



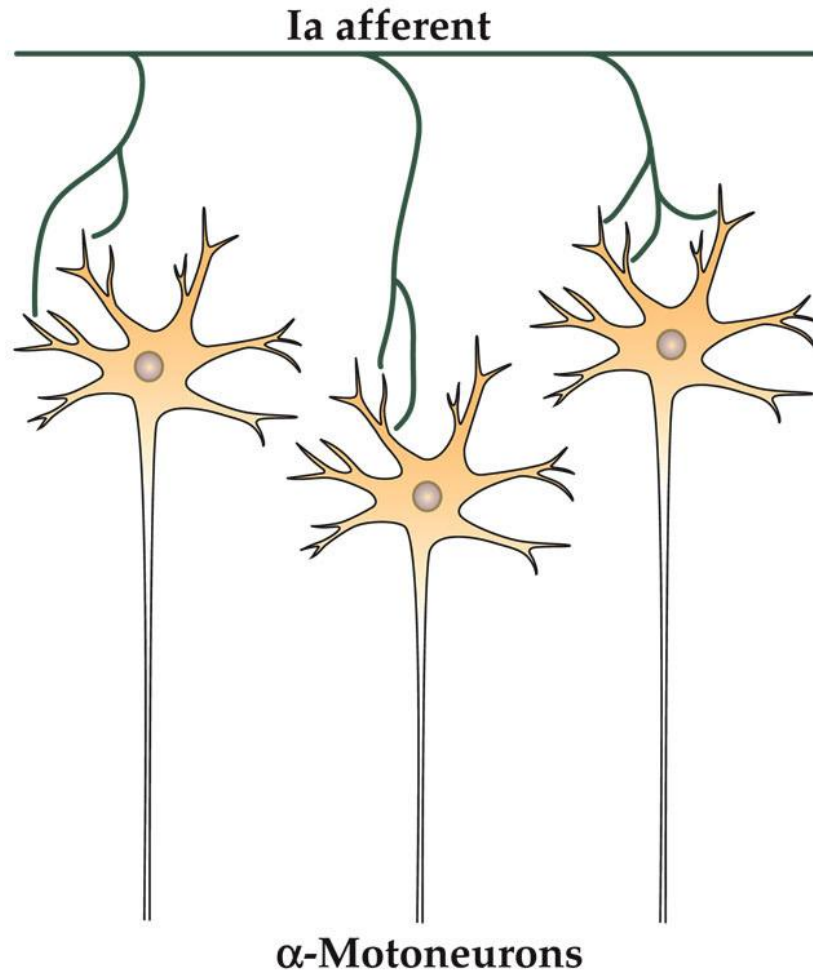
Muscle contraction begins with small motor units being activated (or recruited) first. When more contraction is required progressively larger motor units are recruited

Why? Because small motoneurons are more easily excited than large motoneurons

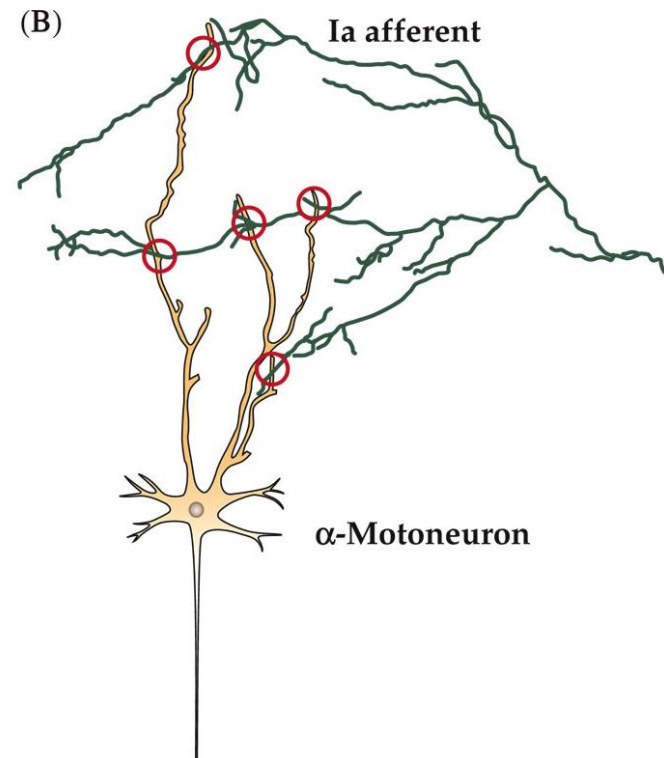




(A)



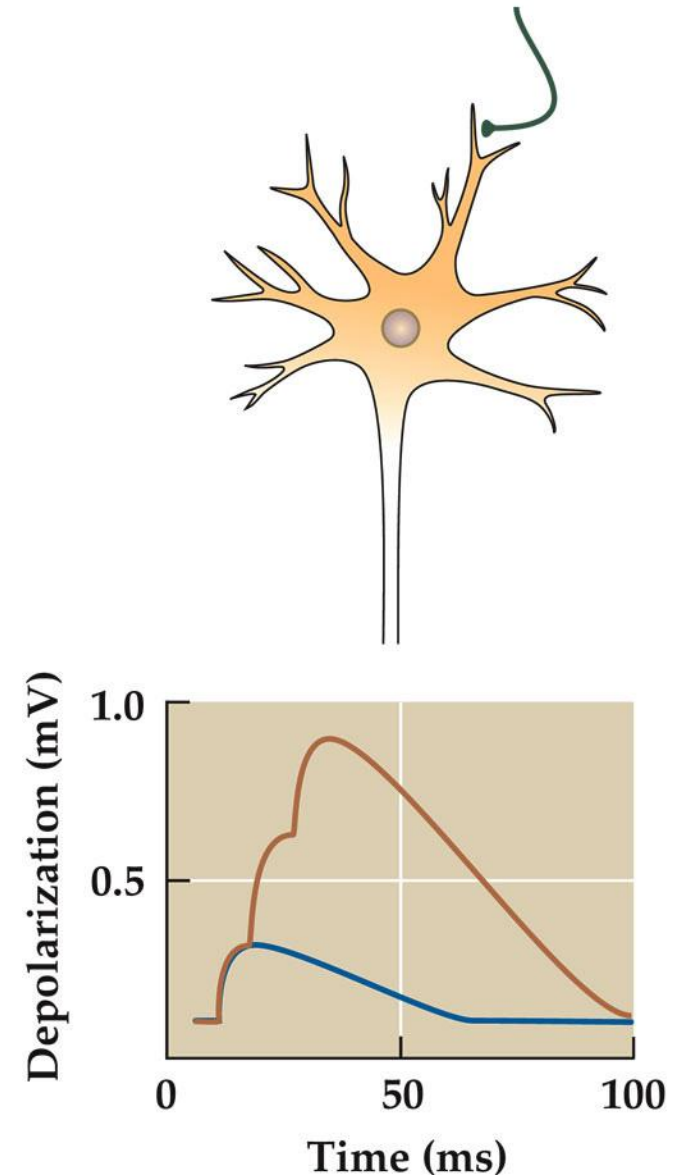
- A. A single muscle spindle fiber (1a) afferent sends branches to several motoneurons
- B. A more detailed view showing synaptic contact (red circles)





- A single action potential in a single afferent produces a synaptic potential in a motoneuron that is only a fraction of a mV (blue)
- When the presynaptic fiber fires three action potentials rapidly in succession, the synaptic potentials (brown) ride on the falling phase of the previous one, increasing the depolarization
- This is called temporal summation

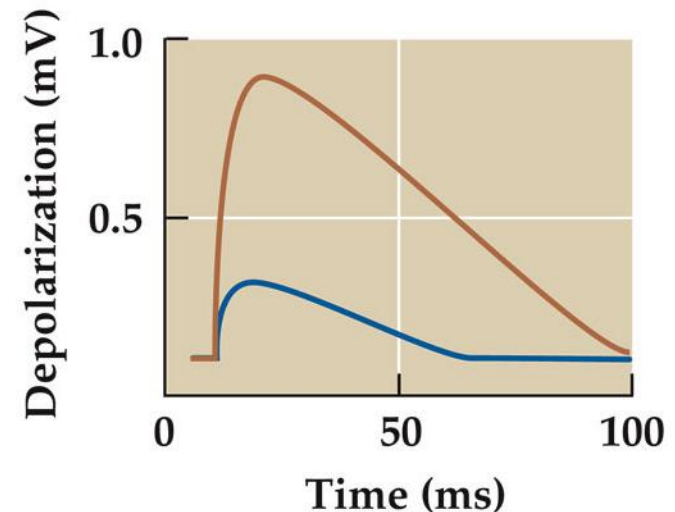
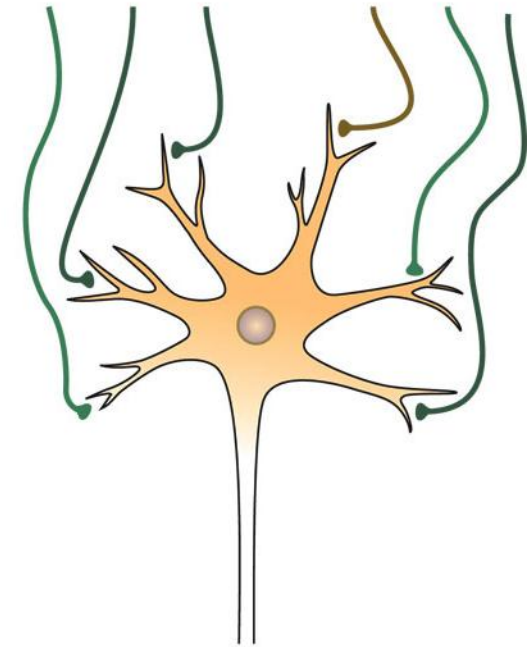
### (A) Temporal summation





- A muscle (such as the soleus in the cat) may have 50 1a afferents converging onto one motoneuron
- A strong stretch of the muscle can activate all the 1a afferents
- The individual EPSPs will spatially summate to depolarize the membrane

(B) Spatial summation







- **Agonists** - Limb movements are produced by the coordinated contraction of groups of muscles that work together. The muscles are called agonists.
- At the same time opposing muscles are made to relax – these muscles are called **antagonists**
- An antagonist muscle opposes the action of another muscle; e.g. relaxing while the other one contracts, thereby producing smooth, coordinated movement.
- **Extensor muscles** – open (or extend) the joints
- **Flexor muscles** – close the joints and pull the limbs toward the body



- A reflex activated by muscle stretch; activate stretch receptors in extensors
- Stretch of muscle spindle generates APs in the group 1a afferent fibers traveling back to the spinal cord
- Group 1a afferents form monosynaptic connections on to the  $\alpha$  motoneuron innervating that same muscle resulting in a reflex contraction
- The same group 1a afferents also form a synapse onto an interneuron that inhibits motoneurons supplying the antagonist muscle (this is a polysynaptic path)

(A) Myotatic reflex

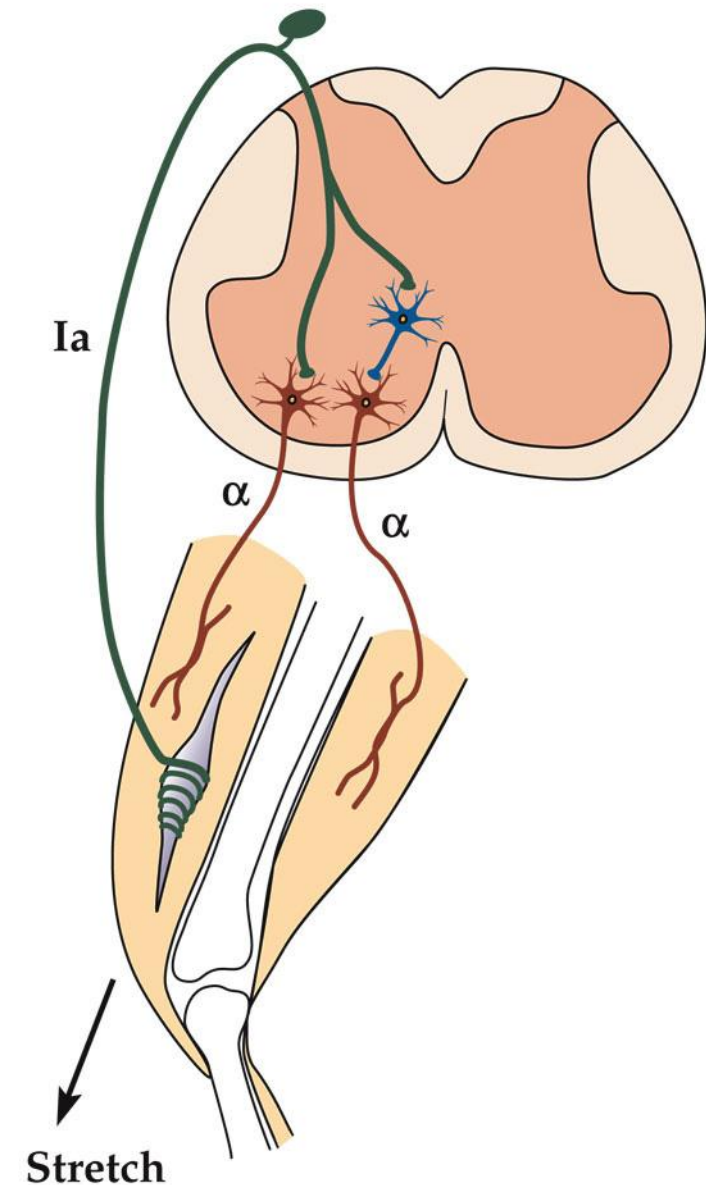


Figure 24.5 Organization of Synaptic Connections for Spinal Reflexes

☞ In addition to the  $\alpha$  motoneurons that sense stretch in the muscle, there are additional stretch receptors termed Golgi tendon organs in the tendon-muscle junction

- These stretch Rs signal through type 1b afferent fibers that make synaptic connections onto  $\alpha$  interneurons that inhibit motoneurons supplying their muscle of origin
- Type 1b afferents also provide excitation to antagonist motoneurons
- The info they provide about muscle tension helps to shape motor pattern and is relayed to higher centres

(B) Inverse myotatic reflex

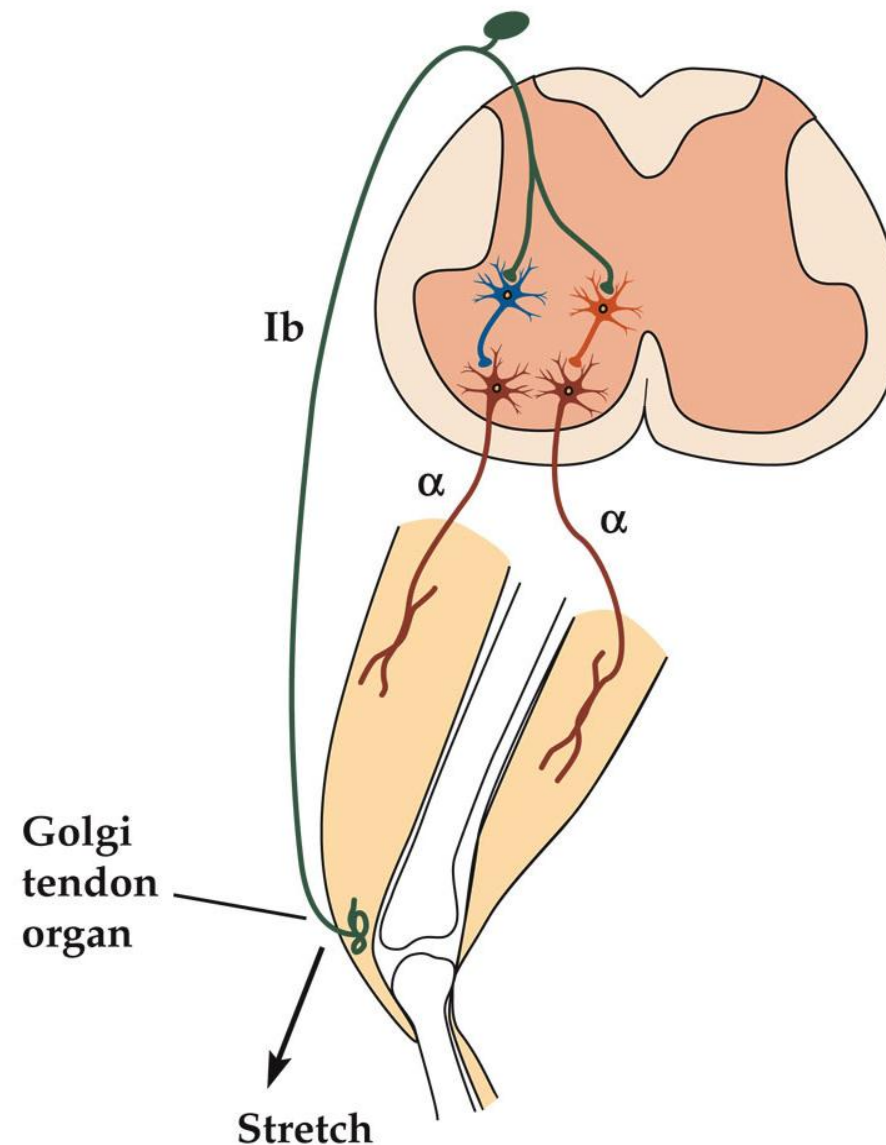
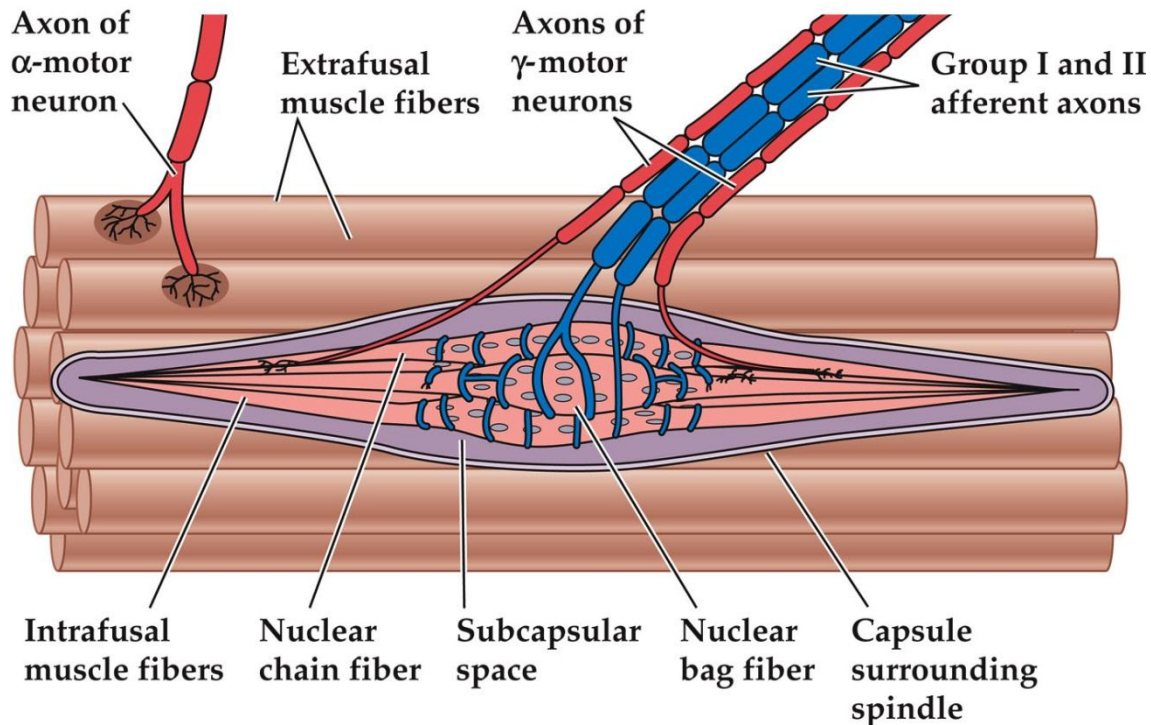



Figure 24.6 Mammalian Muscle Spindle

- The muscle spindle is composed of small intrafusal fibers, is embedded in the bulk of the muscle
- The main muscle is made up of large muscle fibers supplied by  $\alpha$  motoneurons
- Gamma motoneurons supply the intrafusal muscle fibers, and group I and II afferent fibers carry sensory signals from the muscle spindle to the spinal cord

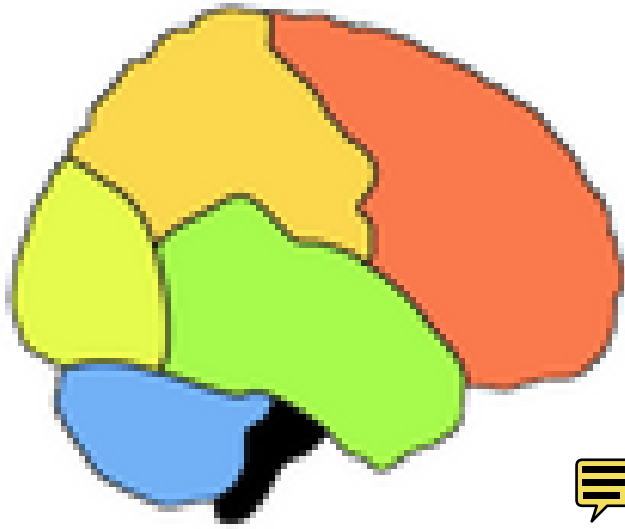


FROM NEURON TO BRAIN 5e, Figure 24.6  
© 2012 Sinauer Associates, Inc.

# Neural organization of motor control is hierarchical

1. *Simplest level*: sensory neurons synapse with motoneurons in the spinal cord to mediate simple reflexes
2. *Central pattern generators*: networks of interneurons in the spinal cord and brainstem coordinating the interplay of multiple motor groups (locomotion, respiration)  

3. **Motor output that is planned and refined by the motor cortex, basal ganglia and cerebellum**

## Lobes of the human cerebral cortex and the cerebellum (blue):



- Occipital lobe (yellow): primarily concerned with vision

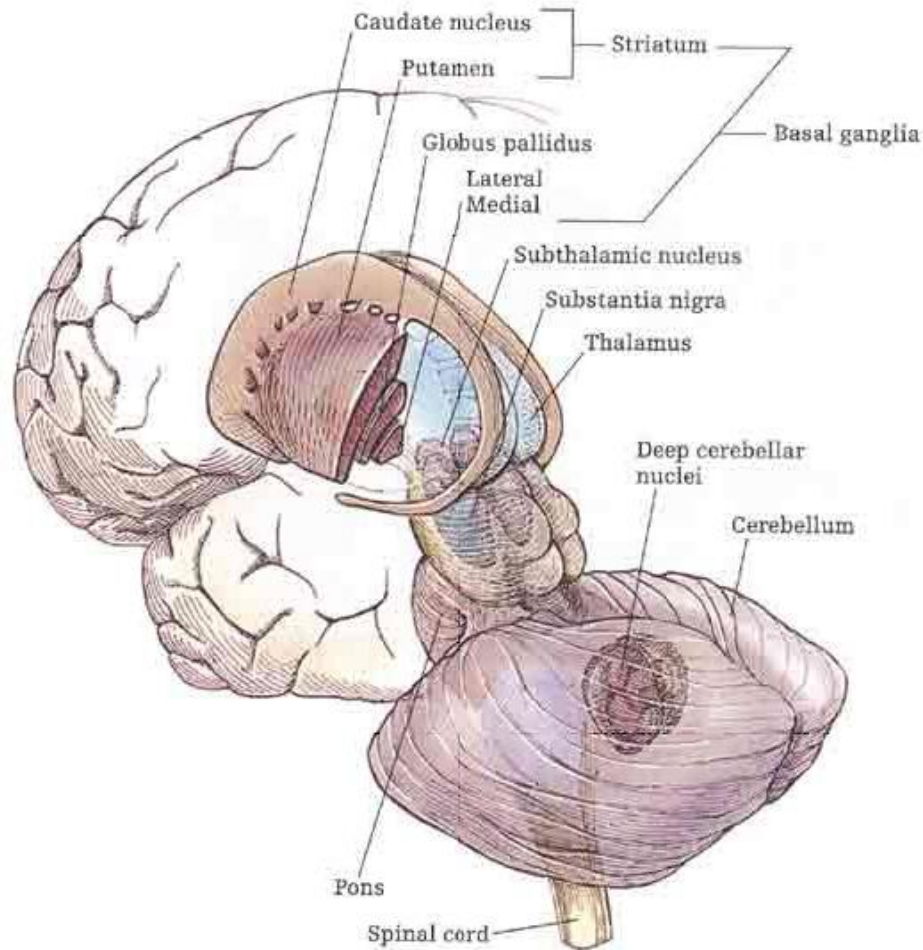
- Parietal lobe (orange): primary somatosensory cortex



- **Frontal lobe (red): primary motor cortex; mediates voluntary movements of limbs and trunk**

- Temporal lobe (green): primary auditory cortex





- The basal ganglia receives cortical projections; projects to frontal lobe; regulates movement and contributes to cognition
- The basal ganglia provides essential modulation of motor output through its complex feedback circuitry
- Ensures timing and coordination of movements

Figure 24.28 The Basal Ganglia



Coronal section through the cerebral hemispheres, continued as a longitudinal section of the brainstem and spinal cord

- Basal ganglia include the caudate nucleus, putamen, and globus pallidus (external and internal divisions)
- Two additional nuclei, the substantia nigra and the subthalamic nucleus, have extensive interconnections with the basal ganglia and are sometimes included with them
- The predominant input to the basal ganglia is from the cortex (left side, blue)
- Outputs from the basal ganglia go to the centroanterior and ventrolateral nuclei of the thalamus, which in turn project to the cortex (right side, red)

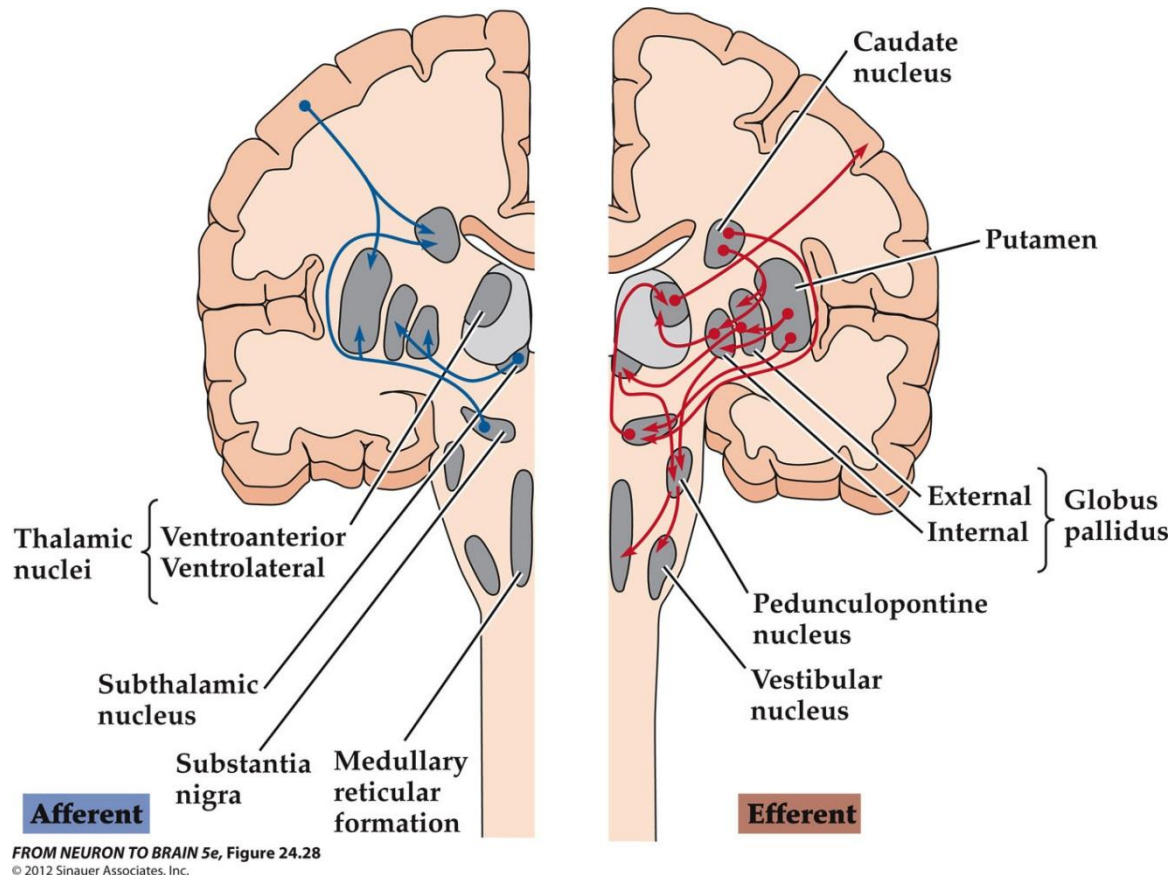
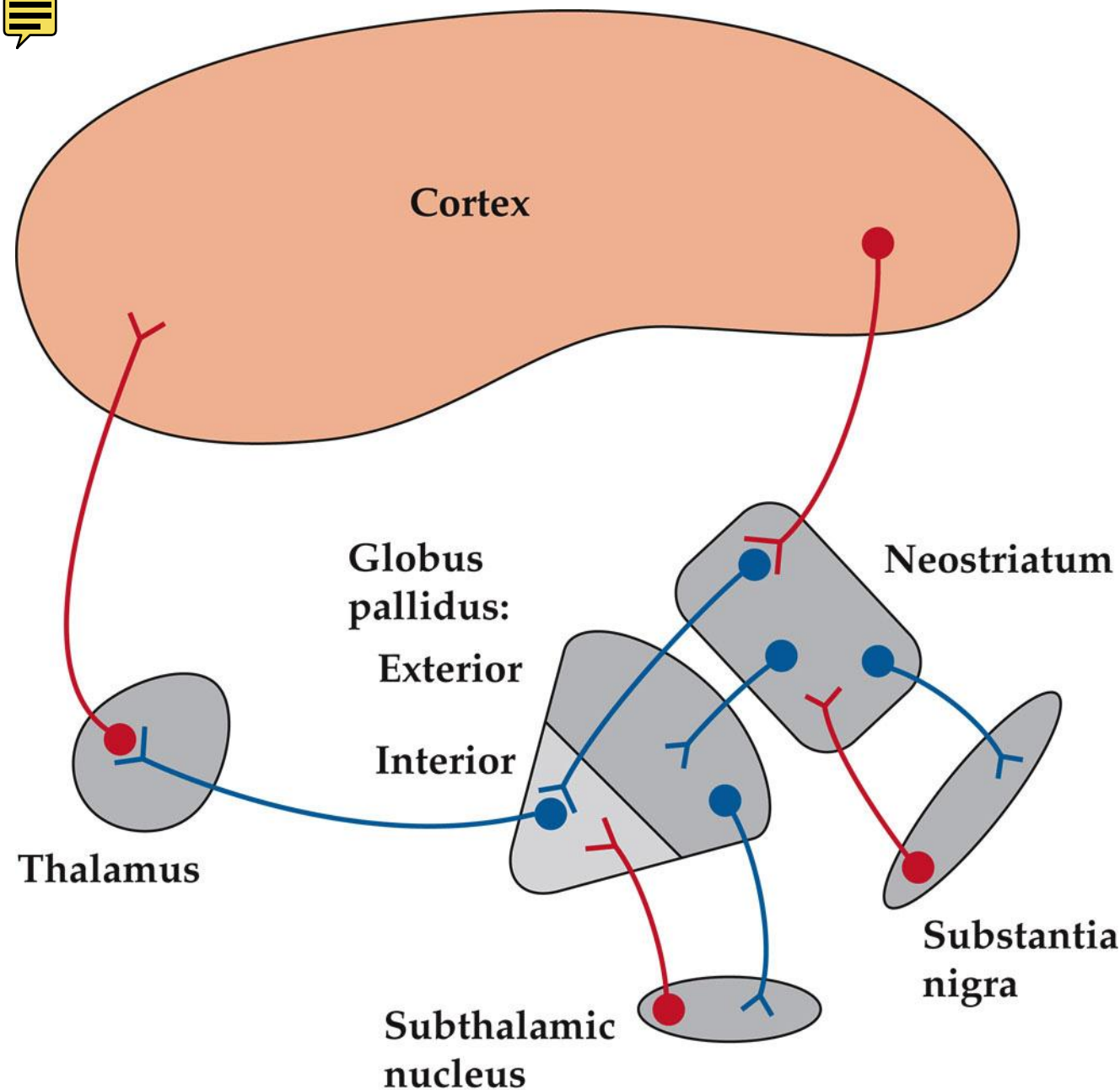
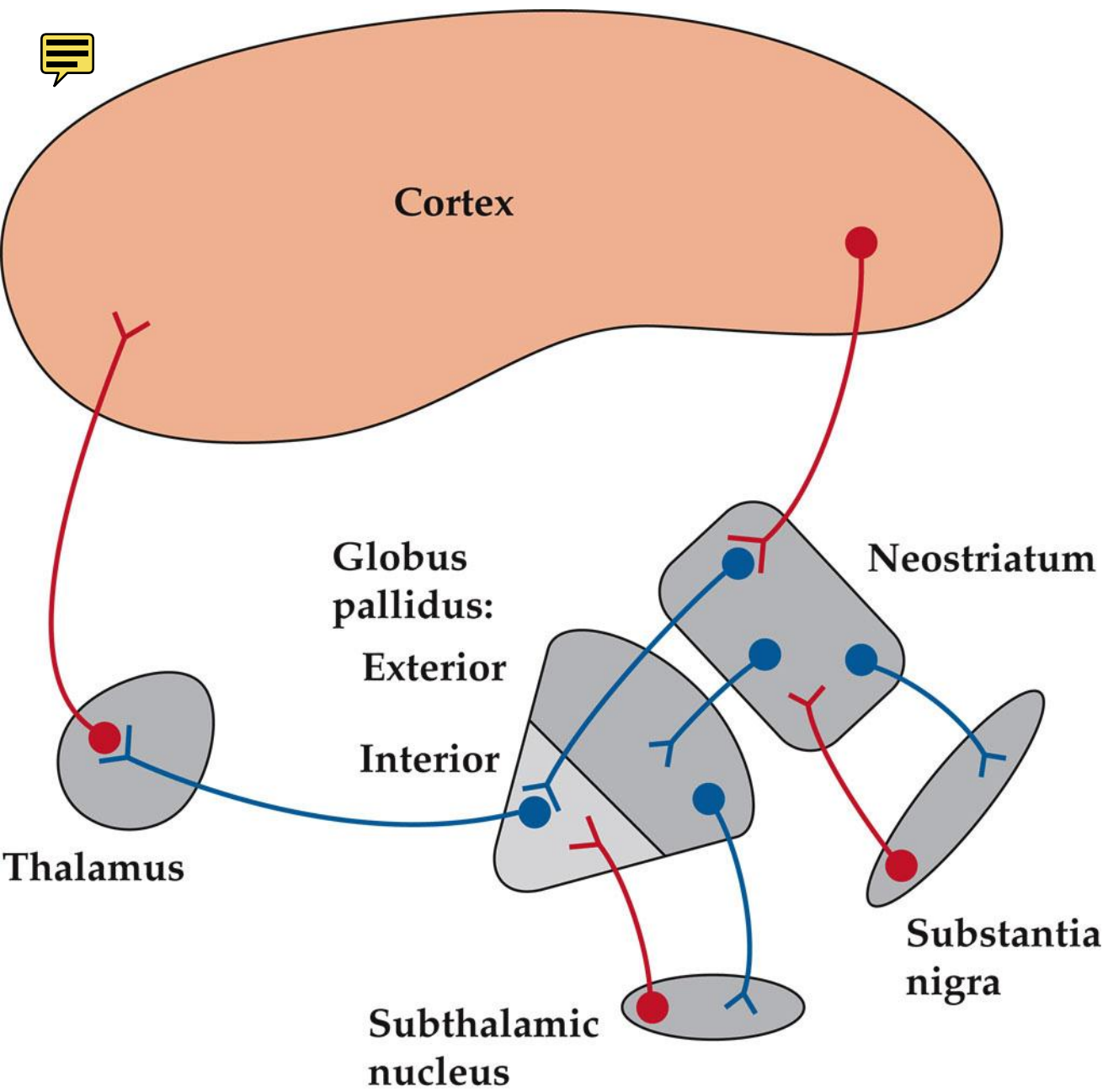


Figure 24.29 Functional Circuits of the Basal Ganglia



- RED – excitatory neurons
- BLUE – inhibitory neurons
- Glutamatergic neurons in cortex excite GABAergic cells of the neostriatum (caudate and putamen)
- Striatal neurons project to the external globus pallidus (the direct pathway) to inhibit GABAergic neurons in those nuclei
- GABAergic neurons of the internal globus pallidus project to and inhibit the thalamus

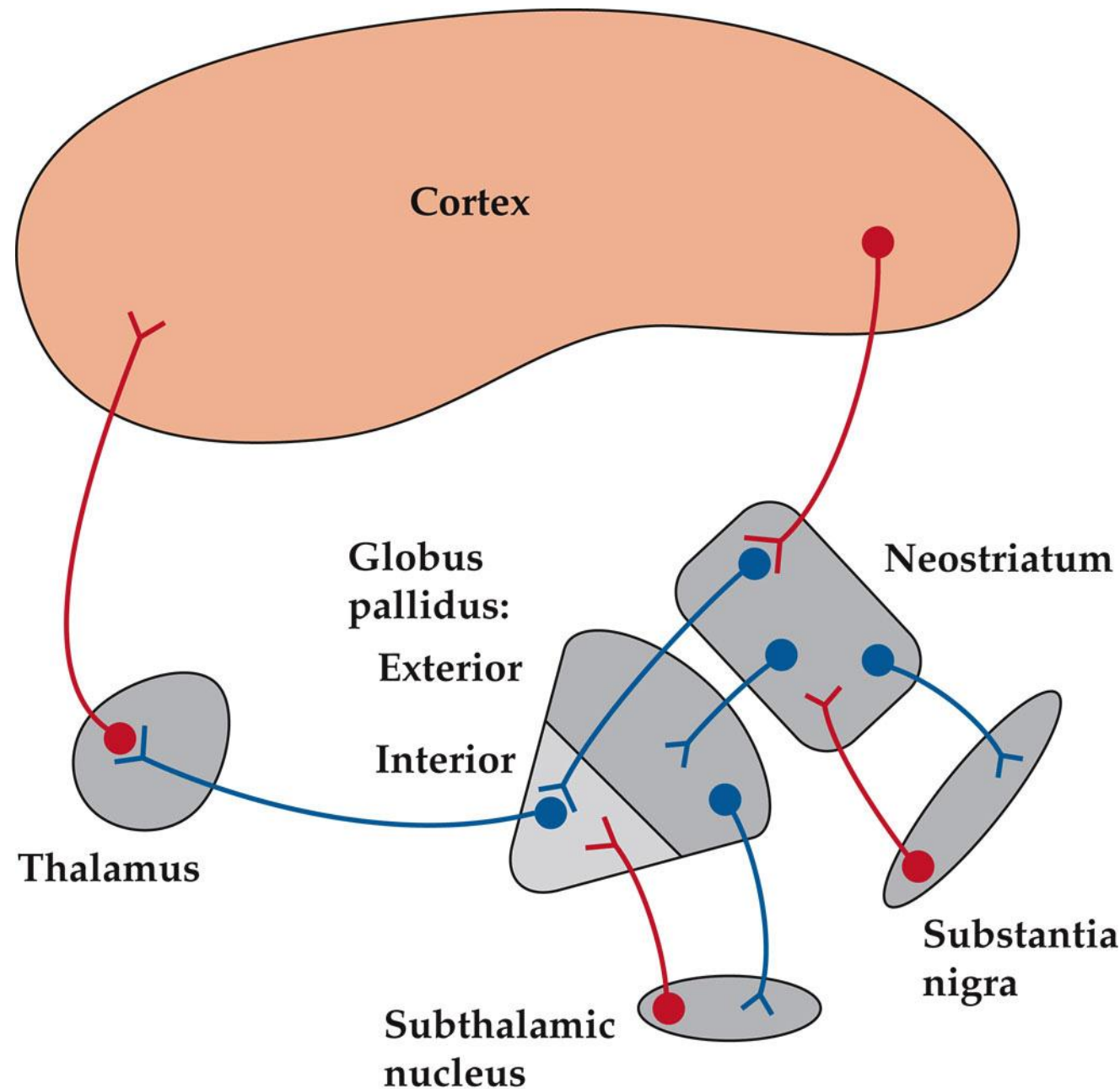
Figure 24.29 Functional Circuits of the Basal Ganglia



- Dopaminergic neurons of the substantia nigra produced net excitation of the striatum
- Glutamatergic neurons of the subthalamic nucleus are inhibited by the projection from the external globus pallidus and excite GABAergic neurons of the internal globus pallidus



Figure 24.29 Functional Circuits of the Basal Ganglia **SUMMARY**



**SUMMARY:**

- Increased cortical activity
- Excitation of the caudate nucleus and the putamen
- Inhibition of the globus pallidus
- *disinhibition* of the thalamus
- Increased activity of the thalamocortical pathway
- Activation of the cortex

## Characterized by:



- a resting tremor that is lost during intended movement
- Increased tone due to simultaneous activation on antagonist muscles
- Difficulty in initiating movements
- Slowness of movement once begun

Dopaminergic neurons of the substantia nigra degenerate decreasing striatal activity and producing less inhibition of the globus pallidus; the increase in activity in the globus pallidus reduces the firing of cells in the thalamus which decreases excitatory input to the motor cortex

