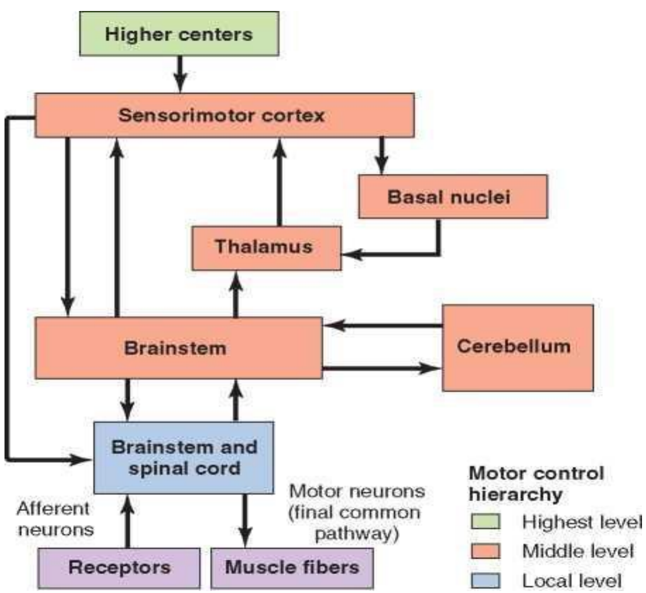
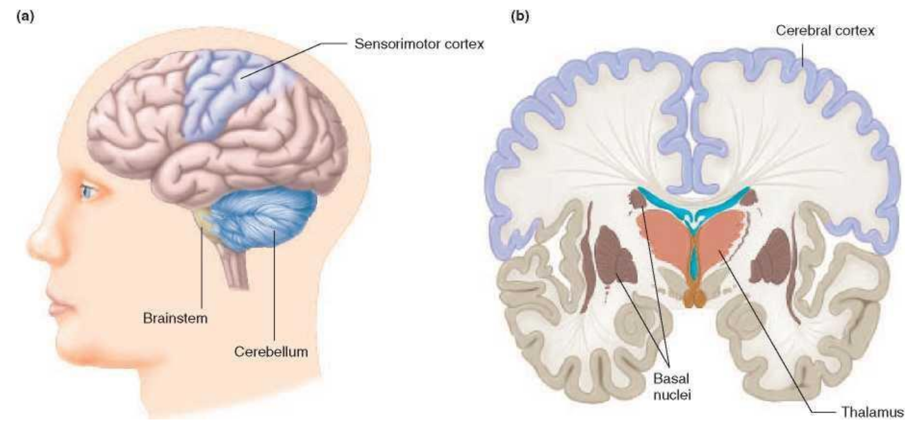
BODY MOVEMENTS

CONTROL OF BODY MOVEMENTS



The conceptual hierarchical organization of the neural systems controlling body movement. All the skeletal muscles of the body are controlled by motor neurons. Sensorimotor cortex includes those parts of the cerebral cortex that act together to control skeletal muscle activity. The middle level of the hierarchy also receives input from the vestibular apparatus and eyes



(a) Side view of the brain showing three of the four components of the middle level of the motor control hierarchy.

(b) Cross section of the brain showing the basal nuclei— part of the subcortical nuclei, the fourth component of the hierarchy's middle level.

VOLUNTARY MOVEMENTS

HIGHER CENTERS

- Function: forms complex plans according to individual's intention and communicates with the middle level via "command neurons."
- Structures: areas involved with memory and emotions, supplementary motor area, and association cortex. All these structures receive and correlate input from many other brain structures.

THE MIDDLE LEVEL

- Function: converts plans received from the highest level to a number of smaller motor programs, which determine the pattern of neural activation required to perform the movement. These programs are broken down into subprograms that determine the movements of individual joints. The programs and subprograms are transmitted through descending pathways to the lowest control level.
- Structures: sensorimotor cortex, cerebellum, parts of basal nuclei, some brainstem nuclei.

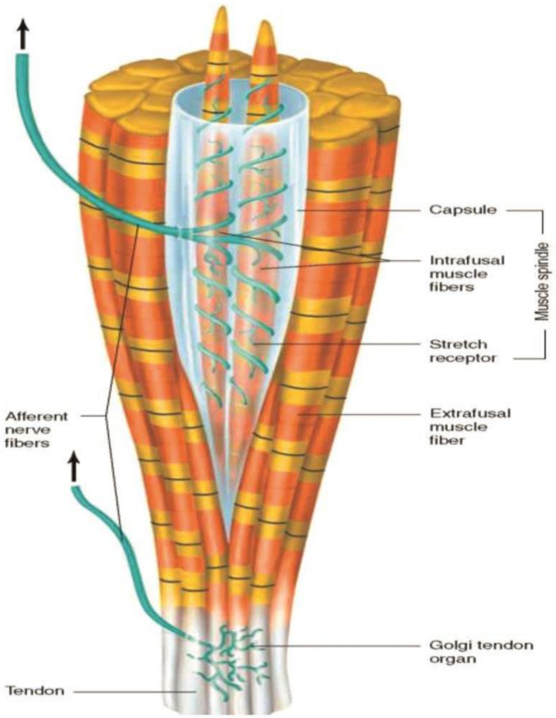
THE LOWEST LEVEL (THE LOCAL LEVEL)

- Function: specifies tension of particular muscles and angle of specific joints at specific times necessary to carry out the programs and subprograms transmitted from the middle control levels.
- Structures: levels of brainstem or spinal cord from which motor neurons exit.

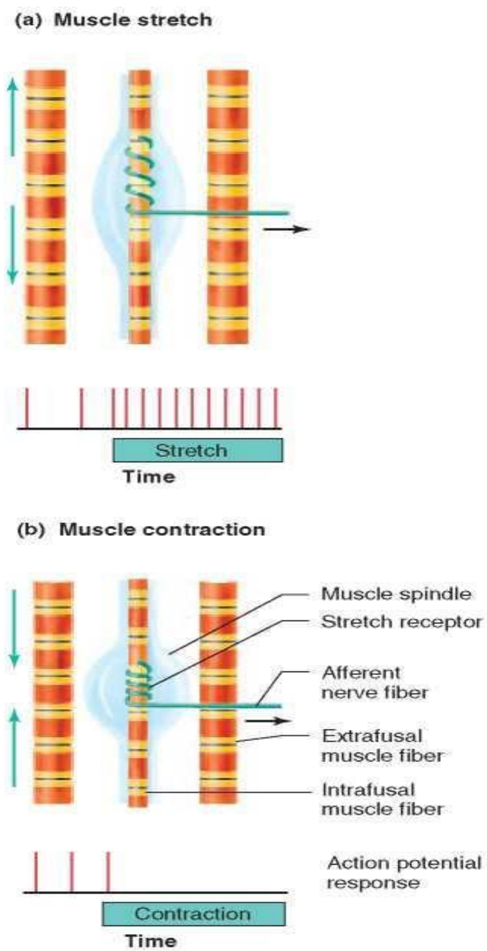
VOLUNTARY AND INVOLUNTARY ACTIONS

- Characteristics of voluntary movement: (1) The movement is accompanied by a conscious awareness of what we are doing and why we are doing it, and (2) our attention is directed toward the action or its purpose. The term "involuntary" describes actions that do not have these characteristics. Unconscious," "automatic," and "reflex" are often taken to be synonyms for "involuntary," although in the motor system the term "reflex" has a more precise meaning.
- Despite attempts to distinguish between voluntary and involuntary actions, almost all motor behavior involves both components, and the distinction between the two cannot be made easily. Even such a highly conscious act involves the unconscious postural support of the hand and forearm and inhibition of the antagonistic muscles, whose activity would oppose the intended action.
- Most motor behavior is neither purely voluntary nor purely involuntary but falls somewhere between these two extremes. Moreover, actions shift along this continuum according to the frequency with which they are performed.

LENGTH-MONITORING SYSTEMS



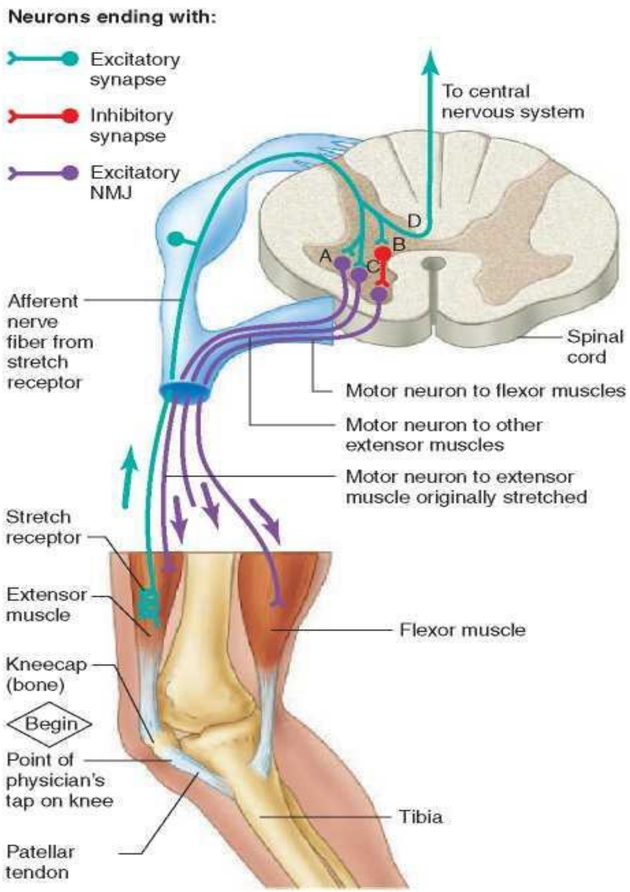
A muscle spindle and Golgi tendon organ. The muscle spindle is exaggerated in size compared to the extrafusal muscle fibers.



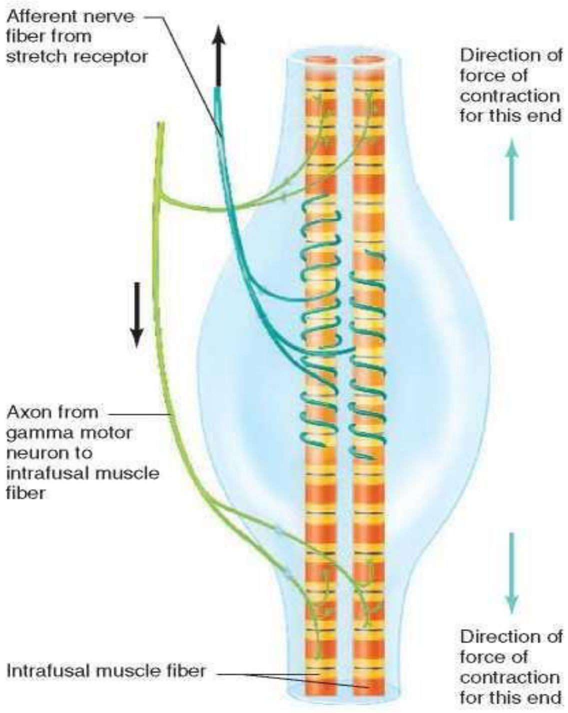
(a) Passive stretch of the muscle activates the spindle stretch receptors and causes an increased rate of action potentials in the afferent nerve.

(b) Contraction of the extrafusal fibers removes tension on the stretch receptors and lowers the rate of action potential firing. Blue arrows indicate direction of force on the muscle spindles

NEURAL PATHWAYS INVOLVED IN THE KNEE JERK REFLEX

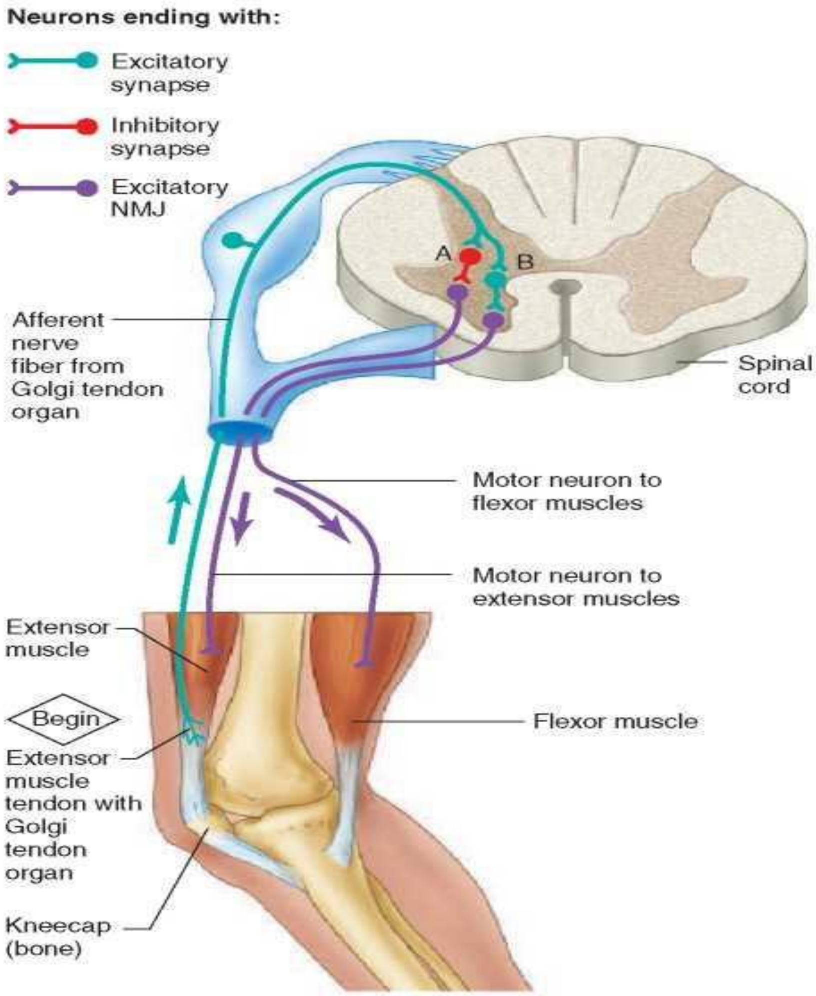


Tapping the patellar tendon stretches the extensor muscle, causing (paths A and C) compensatory contraction of this and other extensor muscles, (path B) relaxation of flexor muscles, and (path D) information about muscle length to be sent to the brain. Arrows indicate direction of action potential propagation.



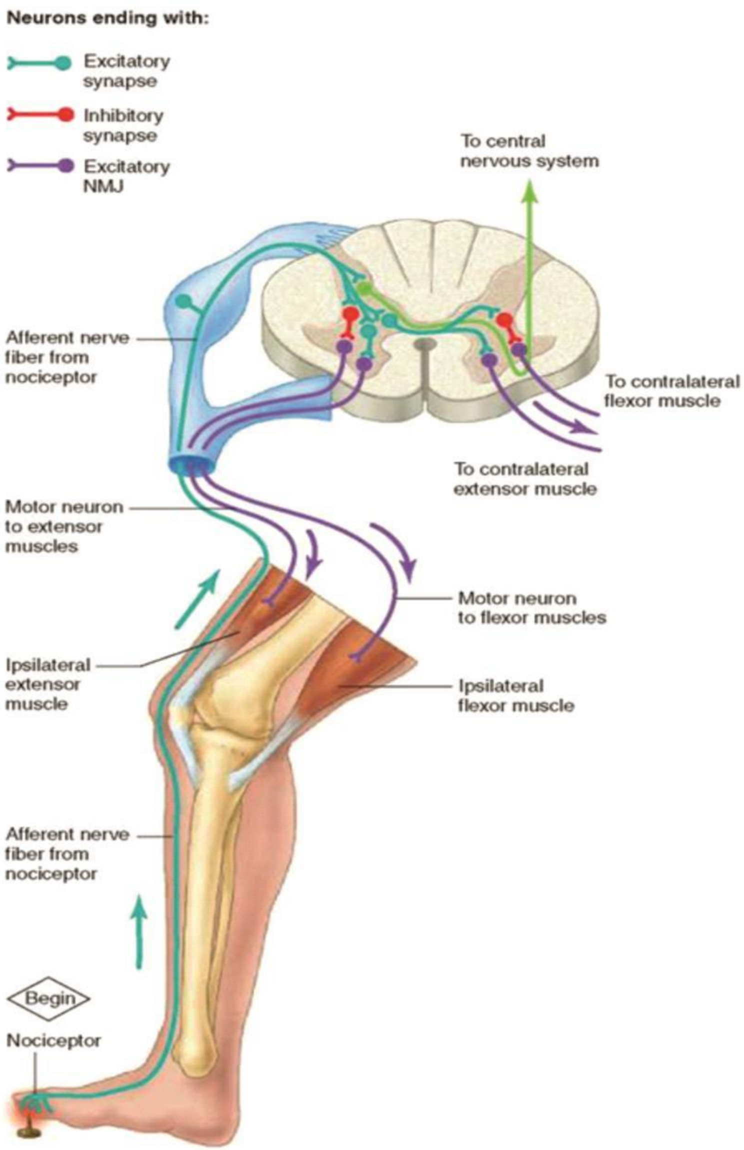
As the ends of the intrafusal fibers contract in response to gamma motor neuron activation, they pull on the center of the fiber and stretch the receptor. The black arrows indicate the direction of action potential propagation

TENSION-MONITORING SYSTEMS



Neural pathways underlying the Golgi tendon organ component of the local control system. In this diagram, contraction of the extensor muscles causes tension in the Golgi tendon organ and increases the rate of action potential firing in the afferent nerve fiber. By way of interneurons, this increased activity results in (path A) inhibition of the motor neuron of the extensor muscle and its synergists and (path B) excitation of flexor muscles' motor neurons. Arrows indicate direction of action potential propagation.

THE WITHDRAWAL REFLEX

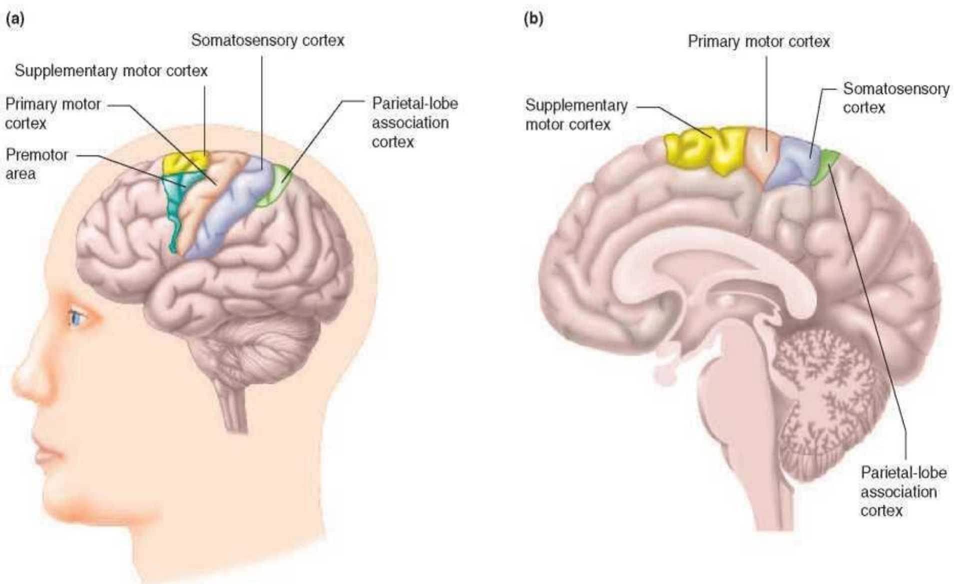


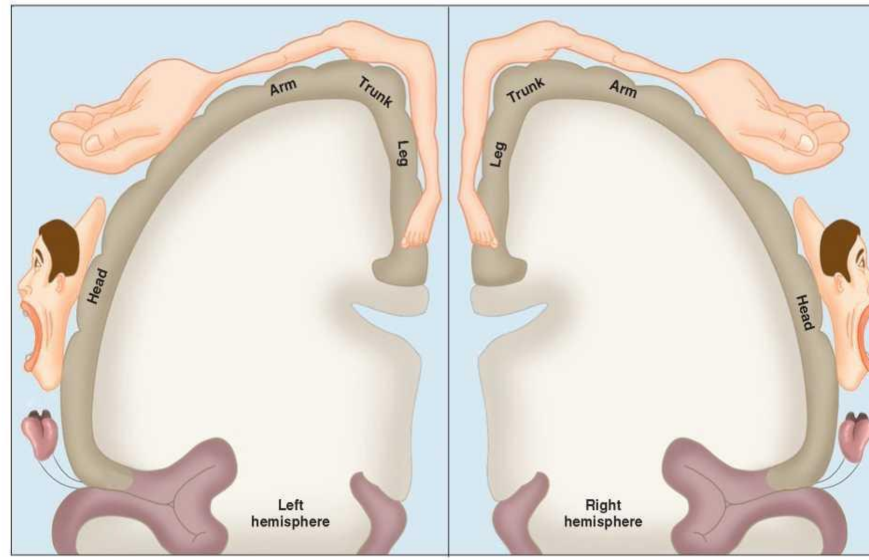
In addition to the afferent information from the spindle stretch receptors and Golgi tendon organs of the activated muscle, other input is fed into the local motor control systems. For example, painful stimulation of the skin activates the ipsilateral flexor motor neurons and inhibits the ipsilateral extensor motor neurons, moving the body part away from the stimulus. The strengthened extension of the contralateral leg means that this leg can support more of the body's weight as the hurt foot is raised from the ground by flexion.

LOCAL CONTROL OF MOTOR NEURONS

- Muscle length and the velocity of changes in length are monitored by muscle spindle stretch receptors.
- Activation of these receptors initiates the stretch reflex, in which motor neurons of ipsilateral antagonists are inhibited and those of the stretched muscle and its synergists are activated.
  This provides negative feedback control of muscle length.
- Tension on the stretch receptors is maintained during muscle contraction by gamma efferent activation to the spindle muscle fibers.
- Alpha and gamma motor neurons are generally coactivated.
- Muscle tension is monitored by Golgi tendon organs, which, via interneurons, activate inhibitory synapses on motor neurons of the contracting muscle and excitatory synapses on motor neurons of ipsilateral antagonists. This provides negative feedback control of muscle tension.
- The withdrawal reflex excites the ipsilateral flexor muscles and inhibits the ipsilateral extensors. The crossed-extensor reflex excites the contralateral extensor muscles during excitation of the ipsilateral flexors.

THE BRAIN MOTOR CENTERS





(a) The major motor areas of cerebral cortex. (b) Midline view of the right side of the brain showing the supplementary motor cortex, which lies in the part of the cerebral cortex that is folded down between the two cerebral hemispheres. Other cortical motor areas also extend onto this area. The premotor, supplementary motor, primary motor, somatosensory, and parietal-lobe association cortexes together make up the sensorimotor cortex.

Representation of major body areas in primary motor cortex. Within the broad areas, however, no one area exclusively controls the movement of a single body region, and there is much overlap and duplication of cortical representation. Relative sizes of body structures are proportional to the number of neurons dedicated to their motor control.

BRAIN MOTOR CENTERS AND DESCENDING PATHWAYS

- Neurons in the motor cortex are anatomically arranged in a somatotopic map.
- Different areas of sensorimotor cortex have different functions, but there is much overlap in activity.
- The basal nuclei form a link in a circuit that originates in and returns to sensorimotor cortex.
- These subcortical nuclei facilitate some motor behaviors and inhibit others.
- The cerebellum coordinates posture and movement and plays a role in motor learning.
- The corticospinal pathways pass directly from the sensorimotor cortex to motor neurons in the spinal cord (or brainstem, in the case of the corticobulbar pathways) or, more commonly, to interneurons near the motor neurons.
- In general, neurons on one side of the brain control muscles on the other side of the body.
- Corticospinal pathways serve predominately fine, precise movements.
- Some corticospinal fibers affect the transmission of information in afferent pathways.
- Other descending pathways arise in the brainstem and are involved mainly in the coordination of large groups of muscles used in posture and locomotion.
- There is some duplication of function between the two descending pathways.

MUSCLE TONE

Muscle tone can be defined as the resistance of skeletal muscle to stretch as an examiner moves the limb or neck of a relaxed subject. The resistance to passive movement is slight and uniform in a normal person, regardless of the speed of the movement. Muscle tone is due both to the passive elastic properties of the muscles and joints and to the degree of on-going alpha motor neuron activity. When a person is deeply relaxed, the alpha motor neuron activity probably makes no contribution to the resistance to stretch. As the person becomes increasingly alert, however, some activation of the alpha motor neurons occurs and muscle tone increases.

ABNORMAL MUSCLE TONE

Abnormally high muscle tone, called *hypertonia,* occurs in individuals with certain disease processes and is seen very clearly when a joint is moved passively at high speeds. The increased resistance is due to a greater-than-normal level of alpha motor neuron activity, which keeps a muscle contracted despite the person's attempt to relax it. Hypertonia is usually found when there are disorders of the descending pathways that normally inhibit the motor neurons. Clinically, the descending pathways and neurons of the motor cortex are often referred to as the upper motor neurons. Abnormalities due to their dysfunction are classed, therefore, as *upper motor neuron disorders.* Thus, hypertonia indicates an upper motor neuron disorder. In this clinical classification, the alpha motor neurons—the true motor neurons—are termed lower motor neurons.

Spasticity is a form of hypertonia in which the muscles do not develop increased tone until they are stretched a bit, and after a brief increase in tone, the contraction subsides for a short time. The period of "give" occurring after a time of resistance is called the *clasp-knife phenomenon.* Spasticity may be accompanied by increased responses of motor reflexes such as the knee jerk, and by decreased coordination and strength of voluntary actions.

Rigidity is a form of hypertonia in which the increased muscle contraction is continual and the resistance to passive stretch is constant (as occurs in the disease tetanus, which is described in detail at the end of this section). Two other forms of hypertonia that can occur suddenly in individual or multiple muscles are *spasms,* which are brief contractions, and *cramps,* which are prolonged and painful.

Hypotonia is a condition of abnormally low muscle tone, accompanied by weakness, atrophy (a decrease in muscle bulk), and decreased or absent reflex responses. Dexterity and coordination are generally preserved unless profound weakness is present. While hypotonia may develop after cerebellar disease, it more frequently accompanies disorders of the alpha motor neurons ("lower motor neurons"), neuromuscular junctions, or the muscles themselves.

UPRIGHT POSTURE AND BALANCE

- The skeleton supporting the body is a system of long bones and a many-jointed spine that cannot stand erect against the forces of gravity without the support given by coordinated muscle activity. The muscles that maintain upright posture—that is, support the body's weight against gravity—are controlled by the brain and by reflex mechanisms that are "wired into" the neural networks of the brainstem and spinal cord. Many of the reflex pathways (for example, the stretch and crossed-extensor reflexes) are used in posture control. Added to the problem of maintaining upright posture is that of maintaining balance. A human being is a very tall structure balanced on a relatively small base, and the center of gravity is quite high, being situated just above the pelvis.

- For stability, the center of gravity must be kept within the base of support provided by the feet. Once the center of gravity has moved beyond this base, the body will fall unless one foot is shifted to broaden the base of support. Yet people can operate under conditions of unstable equilibrium because their balance is protected by complex interacting postural reflexes, all of which we have met previously.

- The afferent pathways of the postural reflexes come from three sources: the eyes, the vestibular apparatus, and the receptors involved in proprioception (joint, muscle, and touch receptors, for example).
- The efferent pathways are the alpha motor neurons to the skeletal muscles, and the integrating centers are neuron networks in the brainstem and spinal cord.

- There are centers in the brain that form an internal representation of the body's geometry, its support conditions, and its orientation with respect to vertical. This internal representation serves two purposes: (1) It serves as a reference frame for the perception of the body's position and orientation in space and for planning actions, and (2) it contributes to stability via the motor controls involved in the maintenance of upright posture.

REVIEW QUESTIONS

1. Describe motor control in terms of the conceptual motor control hierarchy and using the following terms: highest, middle, and lowest levels; motor program; descending pathways, and motor neuron.
2. Draw a muscle spindle within a muscle, labeling the spindle, intrafusal and extrafusal muscle fibers, stretch receptors, afferent fibers, and alpha and gamma efferent fibers.
3. Describe the components of the knee jerk reflex (stimulus, receptor, afferent pathway, integrating center, efferent pathway, effector, and response).
4. Describe the major function of alpha-gamma coactivation.
5. Distinguish among the following areas of the cerebral cortex: sensorimotor, primary motor, premotor, and supplementary motor.
6. Explain how hypertonia might result from disease of the descending pathway.
7. Explain how hypotonia might result from lower motor neuron disease.
8. Explain the role played by the crossed-extensor reflex in postural stability.