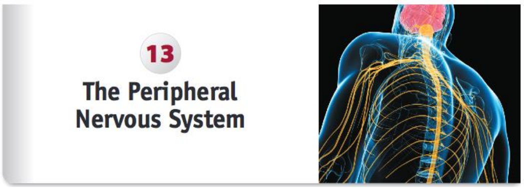


ERIN C. AMERMAN
FLORIDA STATE COLLEGE AT JACKSONVILLE

Lecture Presentation by Suzanne Pundt
University of Texas at Tyler

MODULE 13.1 OVERVIEW OF THE PERIPHERAL NERVOUS SYSTEM

OVERVIEW OF THE PNS

- **Peripheral nervous system** (**PNS**) – links CNS to *body* and to *external environment*
  - PNS *detects* sensory stimuli and *delivers* information to CNS as sensory input
  - CNS *processes* input and *transmits* impulse through PNS to muscle cells and glands as motor output

DIVISIONS OF THE PNS

PNS is classified functionally into 2 divisions:

- **Sensory division** – consists of **sensory** (**afferent**) **neurons** that detect and transmit *sensory stimuli* to CNS; has 2 anatomical subdivisions (**Figure 13.1**):
  - **Somatic sensory division** detects both internal and external stimuli; general sense receptors detect stimuli from *skin*; special sensory receptors detect stimuli from *special sense organs*
  - **Visceral sensory division** relays internal information (like blood pressure) from *organs* of abdominopelvic and thoracic cavities

DIVISIONS OF THE PNS

- **Motor division** – consists of **motor** (**efferent**) **neurons**; carry out *motor functions* of nervous system; subdivisions based on organs that neurons contact (**Figure 13.1**):
  - **Somatic motor division** – responsible for *voluntary* motor functions; composed of **lower motor neurons** (**somatic motor neurons**) which directly trigger *skeletal muscle* contractions
  - **Visceral motor division** (**autonomic motor nervous system**, **ANS**) – responsible for maintaining many aspects of homeostasis by controlling *involuntary motor functions* in body; neurons innervate *cardiac muscle cells*, *smooth muscle cells*, and *secretory cells* of glands

DIVISIONS OF THE PNS

- **Motor division** – consists of **motor** (**efferent**) **neurons**; carry out *motor functions* of nervous system; subdivisions based on organs that neurons contact (**Figure 13.1**) (continued):
  - ANS is further divided into **sympathetic** and **parasympathetic** nervous systems
    - **Sympathetic nervous system** (**fight or flight division**) – involved in homeostasis activities surrounding *physical work* and *visceral responses* of emotions
    - **Parasympathetic system** (**rest and digest division**) – involved in *digestion* and maintaining body's homeostasis at *rest*

Divisions of the PNS

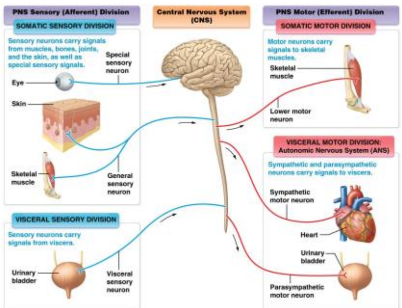


Figure 13.1 The organization of the peripheral nervous system.

Overview of Peripheral Nerves and Associated Ganglia

- **Peripheral nerves** – main organs of PNS; consist of *axons* of many neurons bound together by *connective tissue*
  - Nerves of PNS contact or **innervate** majority of structures in body
  - **Mixed nerves** – contain both sensory and motor neurons
  - **Sensory nerves** – contain only sensory neurons while **motor nerves** contain mostly motor neurons (also some sensory neurons involved in muscle stretch and tension)

Overview of Peripheral Nerves and Associated Ganglia

- **Spinal nerves** – originate from *spinal cord* and innervate structures below head and neck; anatomical structures associated with this group of nerves include (**Figure 13.2a**):
  - Two collections of axons connect PNS with spinal cord's gray matter; **anterior root** consists of *motor neurons* from anterior horn and **posterior root** consists of *sensory neurons* from posterior horn

Overview of Peripheral Nerves and Associated Ganglia

- **Spinal nerves** (continued):
  - Posterior root features a swollen area that houses *cell bodies* of sensory neurons called **posterior root ganglion** (or **dorsal root ganglion**)
  - Posterior and anterior roots *fuse* to form spinal nerve just lateral to posterior root ganglion
  - All 31 pairs of spinal nerves are *mixed nerves*

Overview of Peripheral Nerves and Associated Ganglia

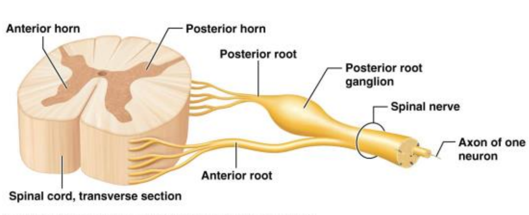


Figure 13.2a The structure of roots and spinal nerves.

Overview of Peripheral Nerves and Associated Ganglia

- Structures associated with spinal nerves (**Figure 13.2bc**):
  - **Epineurium** – outermost layer of connective tissue that holds motor and sensory axons together
  - **Fascicles** – small groups of bundled axons surrounded by connective tissue called **perineurium**
  - Each individual axon within a fascicle is surrounded by its own connective tissue called **endoneurium**

Overview of Peripheral Nerves and Associated Ganglia

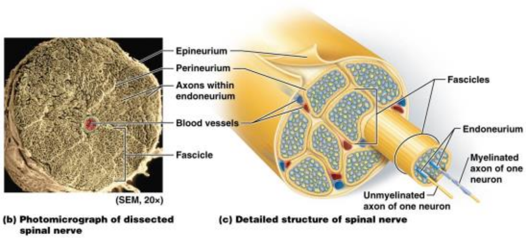


Figure 13.2bc The structure of roots and spinal nerves.

Overview of Peripheral Nerves and Associated Ganglia

- **Cranial nerves** – attach to *brain* and mostly innervate structures in head and neck; not formed by fusion of sensory and motor roots (like spinal nerves); allows for purely sensory, mixed, and mostly motor nerves

Functional Overview of the PNS

Functions of PNS are *integrated* with those of CNS:

- Sensory neurons detect *stimuli* at sensory receptors after which the following events occur:
  - Detected stimuli are transmitted along sensory neuron (spinal or cranial) to cerebral cortex
  - In cortex, sensory information is interpreted, integrated, and an appropriate motor response is selected and initiated (next slide)

Functional Overview of the PNS

- Motor response is *initiated* by commands from motor areas of cerebral cortex, leads to following events:
  - Impulses travel to spinal cord where neurons synapse with lower motor neurons of PNS
  - Lower motor neurons carry impulses to appropriate muscles via cranial or spinal nerves where they trigger *contractions*

Module 13.2 The Cranial Nerves

The Sensory Cranial Nerves

- Three cranial nerves contain axons of only *sensory neurons*:
  - **Olfactory (I)**
  - **Optic (II)**
  - **Vestibulocochlear (VIII)**
- See **Table 13.1** for location and function of these nerves

The Sensory Cranial Nerves

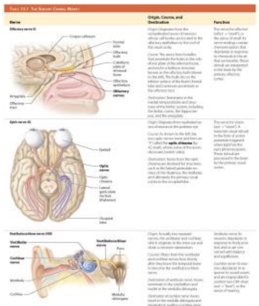


Table 13.1 The Sensory Cranial Nerves.

The Motor Cranial Nerves

- Five cranial nerves contain primarily axons of *motor neurons* with their associated sensory axons responsible for proprioception:
  - **Oculomotor (III)**
  - **Trochlear (IV)**
  - **Abducens (VI)**
  - **Accessory (XI)**
  - **Hypoglossal (XII)**
- See **Table 13.2** for location and function of these nerves

The Motor Cranial Nerves

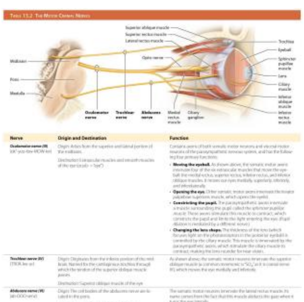


Table 13.2 The Motor Cranial Nerves.

The Motor Cranial Nerves

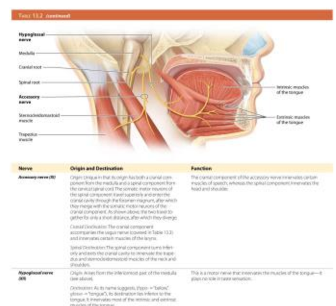


Table 13.2 The Motor Cranial Nerves.

The Mixed Cranial Nerves

- Four cranial nerves contain axons of both *sensory and motor neurons*:
  - **Trigeminal (V)**
  - **Facial (VII)**
  - **Glossopharyngeal (IX)**
  - **Vagus (X)**
- See **Table 13.3** for location and function of these nerves

The Mixed Cranial Nerves

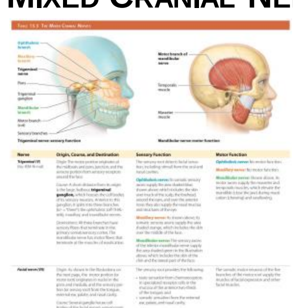


Table 13.3 The Mixed Cranial Nerves.

The Mixed Cranial Nerves

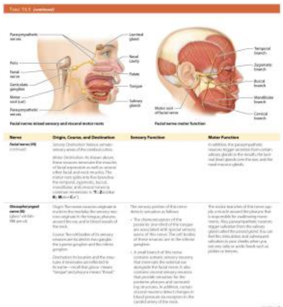


Table 13.3 The Mixed Cranial Nerves.

The Mixed Cranial Nerves

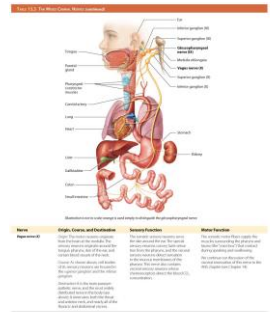


Table 13.3 The Mixed Cranial Nerves.

Overview of Cranial Nerves

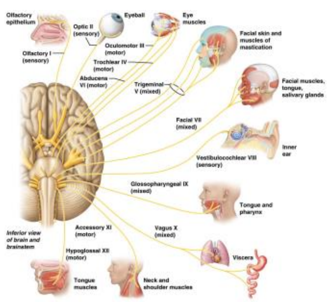


Figure 13.3 Overview of cranial nerves.

Trigeminal Neuralgia

Trigeminal neuralgia (**tic douloureux**) – chronic pain syndrome; involves one or more branches of *trigeminal nerve*

- Patients suffer brief attacks of *intense pain* that last from a few seconds to 2 minutes; typically *unilateral*; may occur several times per day
- Certain stimuli are known to *trigger attacks*, such as chewing and light touch or vibratory stimuli to face (even a light breeze may trigger an attack for certain patients)

Trigeminal Neuralgia

- Neurological examinations of patients are *normal*, and cause of disease is *unknown*
- Pain medications are typically *ineffective*; treatment is instead aimed at reducing aberrant transmission through nerve, often by *severing* it

Bell's Palsy

- Common problem associated with facial nerve is **Bell's palsy**, in which nerve's *motor root* is impaired by a virus, tumor, trauma, or an unknown cause
- Patients have *weakness* or *complete paralysis* of muscles of facial expression on affected side (only)
- Paralysis leads to problems with blinking, closing eye, and making general facial expressions such as smiling

Bell's Palsy

- Other structures innervated by facial nerve may also be affected; *lacrimal gland*, *salivary glands*, and taste sensation from anterior two-thirds of *tongue*
- Typically, individual experiences *rapid onset* of symptoms
- **Treatment** may include *anti-inflammatory medication*, *antiviral medication*, *physical therapy*, and *surgery*; even without treatment, many individuals recover function of paralyzed muscles in about 3 weeks

Study Boost: Remembering the Cranial Nerves

Popular mnemonic to remember cranial nerves:

- **O**h (I, **O**lfactory) **O**nce (II, **O**ptic) **O**ne (III, **O**culomotor) **T**akes (IV, **T**rochlear) **T**he (V, **T**rigeminal) **A**natomy (VI, **A**bducens) **F**inal (VII, **F**acial) **V**ery (VIII, **V**estibulocochlear) **G**ood (IX, **G**lossopharyngeal) **V**acations (X, **V**agus) **A**re (XI, **A**ccessory) **H**appening (XII, **H**ypoglossal)
- Remember that you have one nose (I, olfactory) and two eyes (II, optic)

Study Boost: Remembering the Cranial Nerves

Popular mnemonic cranial nerves by their *main function*:

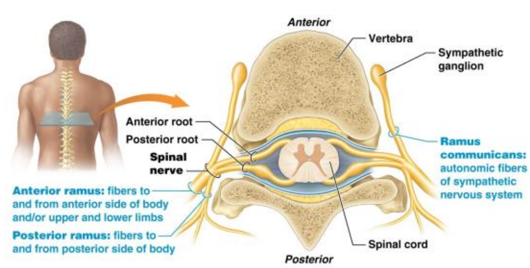
- Some (I, Olfactory—**S**ensory) **S**ay (II, Optic—**S**ensory) **M**oney (III, Oculomotor—**M**otor) **M**atters (IV, Trochlear—**M**otor) **B**ut (V, Trigeminal—**B**oth) **M**y (VI, Abducens—**M**otor) **B**rother (VII, Facial—**B**oth) **S**ays (VIII, Vestibulocochlear—**S**ensory) Big (IX, Glossopharyngeal—**B**oth) **B**rains (X, Vagus—**B**oth) **M**atter (XI, Accessory—**M**otor) **M**ore (XII, Hypoglossal—**M**otor)
- Look closely at names and connect them with *word roots* (see back of book); for example, oculomotor, broken into its two components, oculo-, which means "eye," and -motor, which means "movement"

Module 13.3 The Spinal Nerves

Structure of Spinal Nerves and Spinal Nerve Plexuses

- **Spinal nerve** – short and *divides* into following 2 *mixed* nerves; both carry both somatic motor and sensory information (**Figure 13.4**):
  - **Posterior ramus** – travels to *posterior* side of body
  - **Anterior ramus** – travels to *anterior* side of body and/or to an upper or lower *limb*

Structure of Spinal Nerves and Spinal Nerve Plexuses



(a) Structure of anterior and posterior rami of spinal nerves

Figure 13.4a Structure and function of roots, spinal nerves, and rami.

STRUCTURE OF SPINAL NERVES AND SPINAL NERVE PLEXUSES

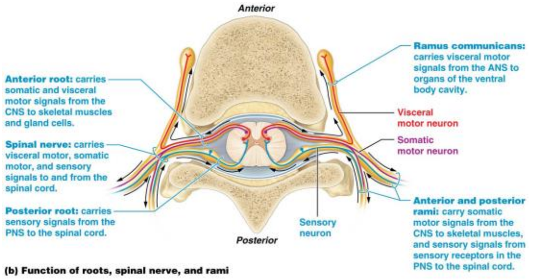


Figure 13.4b Structure and function of roots, spinal nerves, and rami.

STRUCTURE OF SPINAL NERVES AND SPINAL NERVE PLEXUSES

- *31 pairs* of spinal nerves (**Figure 13.5**):
  - 8 pairs of **cervical** nerves
  - 12 pairs of **thoracic** nerves
  - 5 pairs of **lumbar** and **sacral** nerves
  - 1 pair of **coccygeal** nerves
- *Anterior rami* of cervical, lumbar, and sacral spinal nerves each *merge* to form complicated networks of nerves called **nerve plexuses**

STRUCTURE OF SPINAL NERVES AND SPINAL NERVE PLEXUSES

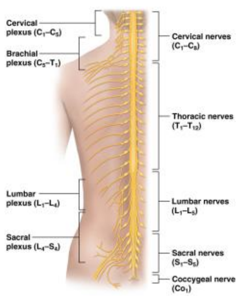


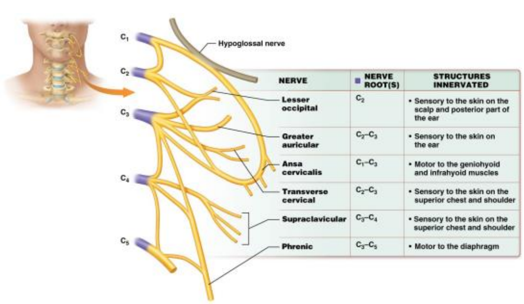
Figure 13.5 Overview of spinal nerves.

CERVICAL PLEXUSES

Right and left **cervical plexuses** are found deep in neck lateral to 1st through 4th cervical vertebrae (**Figure 13.6**)

- Plexus consists of *anterior rami* of **C_1–C_5** and a small contribution from hypoglossal nerve (cranial nerve XII)
- Each nerve in plexus has **cutaneous branches**; innervate skin of *neck* and sections of *head*, *chest*, and *shoulders*
- Motor branches of these nerves innervate specific muscles in *neck*
- **Phrenic nerve** – major motor branch of C_4 with contributions from C_3 and C_5 (**3-4-5 to stay alive**); innervates *diaphragm*

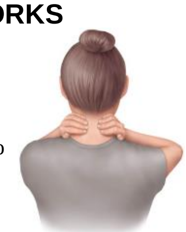
CERVICAL PLEXUSES



NERVE	NERVE ROOT(S)	STRUCTURES INNERVATED
Lesser occipital	C_2	• Sensory to the skin on the scalp and posterior part of the ear
Greater auricular	C_2–C_3	• Sensory to the skin on the ear
Ansa cervicalis	C_1–C_3	• Motor to the geniohyoid and infrahyoid muscles
Transverse cervical	C_2–C_3	• Sensory to the skin on the superior chest and shoulder
Supraclavicular	C_3–C_4	• Sensory to the skin on the superior chest and shoulder
Phrenic	C_3–C_5	• Motor to the diaphragm

Figure 13.6 The cervical plexus.

A HICCUP CURE THAT REALLY WORKS



- **Hiccups** – annoying *spasms* of diaphragm that cause a *forceful inhalation* of air
- Numerous remedies are purported to cure hiccups; none have ever been shown to work reliably; one way to end many cases of hiccups involves the **phrenic nerve**

A Hiccup Cure That Really Works

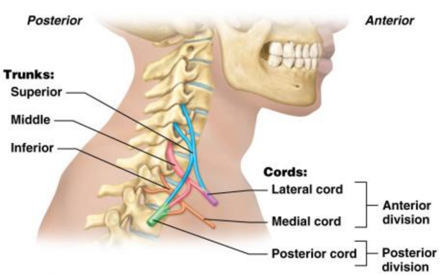
- Find approximate area of cervical vertebrae 3–5 (roughly in middle of neck); place fingers about 1 cm lateral to vertebral column on both sides
- Apply *firm pressure* to muscles of neck that overlie phrenic nerve until hiccups stop, in about 5–10 seconds
- Pressure *interrupts* aberrant impulses that are causing diaphragm to contract inappropriately; pressure is not adequate to stop nerve from *firing* completely or interfere with *breathing*

Brachial Plexuses

Right and left **brachial plexuses** – lateral to 5th cervical through 1st thoracic vertebrae; provide motor and sensory innervation to *upper limbs*; includes nerve roots from C_1–T_1 (**Figure 13.7**)

- Brachial plexus begins with formation of large nerve **trunks**
  - C_5 and C_6 typically unite to form **superior trunk**
  - C_7 usually forms the **middle trunk**
  - C_8 and T_1 usually unite to form the **inferior trunk**

Brachial Plexuses



Brachial Plexuses

- Each trunk *splits* into an anterior and a posterior **division**; become **cords** of plexus (**Figure 13.7a**)
  - Anterior division of inferior trunk forms **medial cord** that descends down *medial arm*
  - Anterior divisions of superior and middle trunks combine to form **lateral cord**, which descends down *lateral arm*
  - Posterior divisions of each trunk unite to form **posterior cord**, which lies in *posterior arm*

Brachial Plexuses

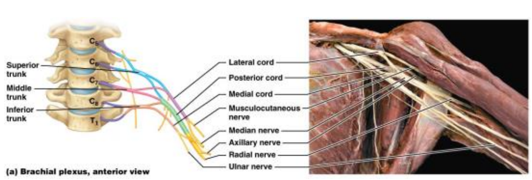


Figure 13.7a The brachial plexus.

Brachial Plexuses

- Five *major nerves* of brachial plexus (**Figure 13.7b**):
  - **Axillary nerve** – branch of posterior cord; serves structures near axilla including deltoid and teres minor muscles and skin over deltoid region
  - **Radial nerve** – continuation of posterior cord as it descends in posterior arm; innervates triceps brachii muscle and most of extensor muscles of forearm; also innervates skin over posterior thumb, 2nd digit, 3rd digit, and lateral half of 4th digit

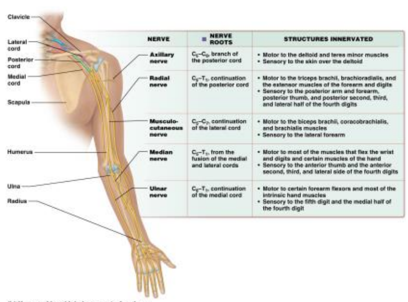
BRACHIAL PLEXUSES

- Five *major nerves* of brachial plexus (continued):
  - **Musculocutaneous nerve** – continuation of lateral cord; innervates anterior arm muscles, including biceps brachii, and skin covering lateral arm
  - **Median nerve** – derived from fusion of lateral and medial cords; travels down middle of arm and forearm; innervates wrist and digital flexors, some intrinsic muscles of hand and skin over anterior thumb, 2nd, 3rd digits, and lateral half of 4th digit

BRACHIAL PLEXUSES

- Five *major nerves* of brachial plexus (continued):
  - **Ulnar nerve** – continuation of medial cord; travels near elbow where it enters forearm to innervate flexor muscles in forearm (not innervated by median nerve), most of intrinsic hand muscles, and skin of 5th digit and medial side of 4th digit

BRACHIAL PLEXUSES



NERVE	NERVE ROOTS	STRUCTURES INNERVATED
Axillary nerve	C_5–C_6, branch of the posterior cord	• Motor to the deltoid and teres minor muscles • Sensory to the skin over the deltoid
Radial nerve	C_5–T_1, continuation of the posterior cord	• Motor to the triceps brachii, brachioradialis, and the extensor muscles of the forearm and digits • Sensory to the posterior arm and forearm, posterior thumb, and posterior second, third, and lateral half of the fourth digits
Musculo-cutaneous nerve	C_5–C_7, continuation of the lateral cord	• Motor to the biceps brachii, coracobrachialis, and brachialis muscles • Sensory to the lateral forearm
Median nerve	C_5–T_1, from the fusion of the medial and lateral cords	• Motor to most of the muscles that flex the wrist and digits and certain muscles of the hand • Sensory to the anterior thumb and the anterior second, third, and lateral side of the fourth digits
Ulnar nerve	C_8–T_1, continuation of the medial cord	• Motor to certain forearm flexors and most of the intrinsic hand muscles • Sensory to the fifth digit and the medial half of the fourth digit

Figure 13.7b The brachial plexus.

THORACIC SPINAL NERVES

Thoracic spinal nerves do not form plexuses, *except* T_1

- Each *posterior ramus* innervates deep back muscles
- Each *anterior ramus* travels between two ribs as an **intercostal nerve**

LUMBAR PLEXUSES

Left and right **lumbar plexuses** are derived from anterior rami of L_1–L_5; anterior to vertebrae; embedded deep within psoas muscle; branches innervate *pelvic structures* and *lower extremity* after splitting into 2 divisions

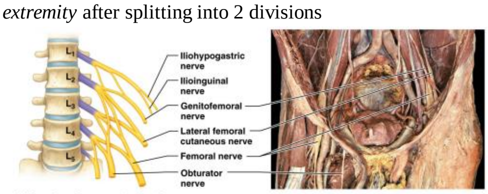


Figure 13.8a The lumbar plexus.

LUMBAR PLEXUSES

- Lumbar plexus divisions:
  - **Obturator nerve** – anterior division's largest member
    - Enters thigh from pelvis via **obturator foramen**
    - Branches of nerve innervate adductor muscles in thigh, hip joint, and skin over medial aspect of thigh

Lumbar Plexuses

- Lumbar plexus divisions (continued):
  - **Femoral nerve**
    - Posterior division's largest member; largest branch of lumbar plexus
    - Travels from psoas, through pelvis and under inguinal ligament to enter thigh where it innervates: anterior thigh muscles and skin over anterior and medial thigh and leg, as well as knee joint

Lumbar Plexuses

NERVE	NERVE ROOTS	STRUCTURES INNERVATED
Iliohypogastric nerve	L_1	• Motor to the transversus abdominus and internal oblique muscles • Sensory to the skin over the lateral gluteal region and the suprapubic region
Ilioinguinal nerve	L_1	• Motor to the transversus abdominus and internal oblique muscles • Sensory to the medial thigh, scrotum (males), and labia majora (females)
Genitofemoral nerve	L_1–L_2	• Motor to the cremaster muscle (males) • Sensory to the anteromedial thigh, scrotum (males), and labia majora (females)
Femoral nerve	L_2–L_4, posterior division	• Motor to the quadriceps femoris, iliopsoas, and sartorius muscles • Sensory to the anterior thigh, medial thigh, medial leg, and foot
Lateral femoral cutaneous nerve	L_2–L_3	• Sensory to the anterolateral thigh
Obturator nerve	L_2–L_4, anterior division	• Motor to the thigh adductors and gracilis muscle • Sensory to the superomedial thigh

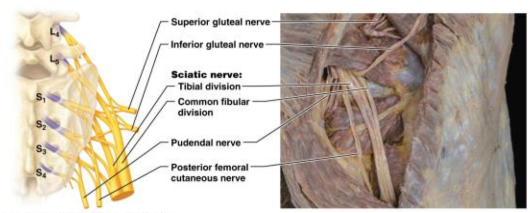
(b) Nerves of lumbar plexus, anterior view

Figure 13.8b The lumbar plexus.

Sacral Plexuses

Right and left **sacral plexuses** are formed from anterior rami of spinal nerves L_4–S_4; nerve branches innervate structures of *pelvis*, *gluteal region*, and much of *lower extremity*; each plexus is divided into anterior and posterior divisions (**Figure 13.9**)

Sacral Plexuses



(a) Sacral plexus, posterior view

Figure 13.9a The sacral plexus.

Sacral Plexuses

- Sacral plexus divisions:
  - **Sciatic nerve** – *longest* and *largest* nerve in body; contains axons from both anterior and posterior divisions of sacral plexus (**Figure 13.9a**)
    - Travels through greater sciatic notch in pelvis into thigh, passing between greater trochanter and ischial tuberosity
    - Innervates hip joint in posterior thigh before it divides into tibial and common fibular nerves

Sacral Plexuses

- Sacral plexus divisions (continued):
  - **Tibial nerve** – larger branch of sciatic nerve; contains axons from anterior division of sacral plexus (**Figure 13.9b**)
    - Branches innervate most of hamstring muscles as nerve descends distally
    - Innervates parts of knee and ankle joints as well as plantar flexor muscles such as gastrocnemius
    - Smaller nerve branches serve posterior and lateral skin of leg as well as skin and muscles of foot

Sacral Plexuses

- Sacral plexus divisions (continued):
  - Smaller **common fibular nerve** (**common peroneal**) – made up of axons from posterior division of sacral plexus
    - Descends along lateral leg to supply part of knee joint and skin of anterior and distal leg
    - Divides into superficial and deep branches; superficial branch serves lateral leg and dorsum of foot; deep branch supplies ankle dorsiflexors and two muscles on dorsum of foot

Sacral Plexuses

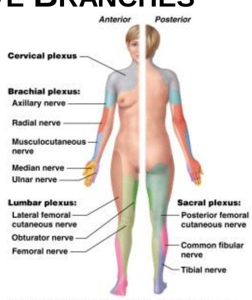
NERVE	NERVE ROOTS	STRUCTURES INNERVATED
Superior gluteal nerve	L_4–S_1	• Motor to the gluteus medius, gluteus minimus, and tensor fasciae latae muscles
Inferior gluteal nerve	L_5–S_2	• Motor to the gluteus maximus muscle
Pudendal nerve	L_4–S_3	• Sensory to the hip joint
Posterior femoral cutaneous nerve	S_2–S_4	• Motor to the muscles of the pelvic floor, the external anal sphincter, and the external urethral sphincter • Sensory to the skin of the external genitalia
Sciatic nerve	S_1–S_3	• Sensory to the skin of the posterior thigh
Common fibular nerve	L_4–S_2, terminal branch of sciatic nerve	• Motor to the lateral leg muscles (superficial branch), the anterior leg muscles, and two foot muscles (deep branch) • Sensory to the knee joint, the skin of the anteroinferior leg, and the dorsum of foot
Tibial nerve	L_4–S_3, terminal branch of sciatic nerve	• Motor to the hamstring muscles, posterior leg muscles, and plantar foot muscles • Sensory to the knee joint, ankle joint, skin of the posterior and lateral leg (via the sural nerve), and skin of the plantar surface of the foot

(b) Nerves of sacral plexus, posterior view

Figure 13.9b The sacral plexus.

Summary of the Distribution of Spinal Nerve Branches

Figure 13.10a summarizes *cutaneous distribution* of spinal plexuses, indicating areas of skin from which these nerves carry *sensory information*

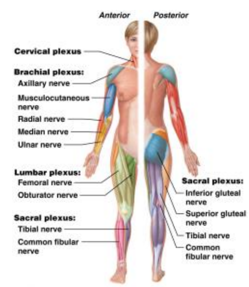


(a) Cutaneous distribution of spinal nerve plexuses

Figure 13.10a The distribution of spinal nerve branches.

Summary of the Distribution of Spinal Nerve Branches

Figure 13.10b illustrates *motor distribution* of these plexuses, showing to which groups of muscles these nerves carry *motor signals*



(b) Motor distribution of spinal nerve plexuses

Figure 13.10b The distribution of spinal nerve branches.

Module 13.4 Sensation Part II: Role of the PNS in Sensation

From PNS to CNS: Sensory Reception and Receptors

- Stimuli are first detected by *sensory neurons*; from that point stimulus is transmitted by sensory neurons to CNS where stimulus is *integrated* and *interpreted* by CNS neurons (**Figure 13.11**)

From PNS to CNS: Sensory Reception and Receptors

- **Sensory transduction** – process where *stimulus* is converted into an *electrical signal* (**Figure 13.11**):
  - Ion channels in axolemma are closed → stimulus is detected by a sensory receptor → sodium ion channels open → sodium ions flow into axoplasm → temporary depolarization (**receptor potential**)
  - If <u>enough</u> sodium ion enters, membrane potential may reach *threshold* → **voltage-gated sodium ion channels** open → **action potential** is propagated along axon toward CNS

From PNS to CNS: Sensory Reception and Receptors

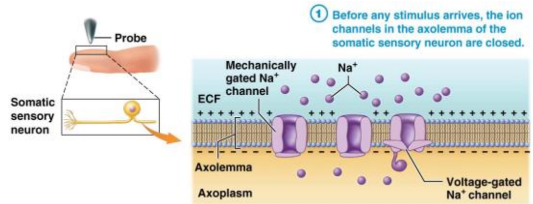


Figure 13.11 Sensory transduction.

From PNS to CNS: Sensory Reception and Receptors

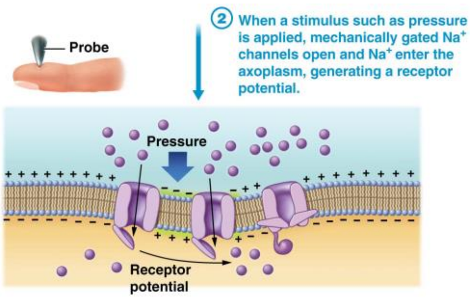


Figure 13.11 Sensory transduction.

From PNS to CNS: Sensory Reception and Receptors

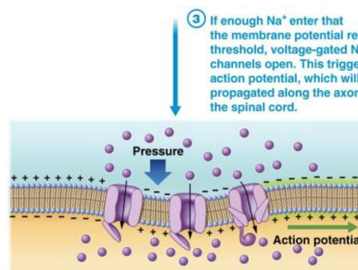


Figure 13.11 Sensory transduction.

From PNS to CNS: Sensory Reception and Receptors

- **Sensory transduction** (continued):
  - **Rapidly adapting receptors** respond *rapidly* with *high intensity* to stimuli but stop sending signals after a certain time period (called **adaptation**); receptors detect *initiation* of stimuli but ignore *ongoing* stimuli
  - **Slowly adapting receptors** respond to stimuli with constant action potentials that <u>don't</u> *diminish* over time

Classification of Sensory Receptors

- **Sensory receptors** exist in many *forms*:
  - **Encapsulated nerve endings** are surrounded by specialized *supportive cells*
  - **Free nerve endings** <u>lack</u> *supportive cells*

Classification of Sensory Receptors

- Sensory receptors can be sorted into following classifications by *location of stimuli* they detect:
  - **Exteroceptors** – usually close to body's surface; detect stimuli originating from *outside* body
  - **Interoceptors** – usually found within body's interior; detect stimuli originating from *within* body itself

Classification of Sensory Receptors

- Sensory receptors can be classified by *type of stimuli* that causes them to depolarize and generate a receptor potential:
  - **Mechanoreceptors** – encapsulated interoceptors or exteroceptors found in musculoskeletal system, skin, and in many other organs; depolarize in response to anything that *mechanically deforms* tissue where receptors are found; **mechanically gated ion channels** allow for sensory transduction from *vibration*, *light touch*, *stretch*, and *pressure*

Classification of Sensory Receptors

- Sensory receptors can be classified by *type of stimuli* that causes them to depolarize and generate a receptor potential (continued):
  - **Thermoreceptors** – exteroceptors, most of which are slowly adapting receptors; depolarize in response to *temperature changes*; <u>separate</u> receptors detect *hot* and *cold*
  - **Chemoreceptors** – can be either interoceptors or exteroceptors; depolarize in response to binding to *specific chemicals* (in body fluids or in air); generate a receptor potential as sodium ion channels open

Classification of Sensory Receptors

- Sensory receptors can be classified by *type of stimuli* that causes them to depolarize and generate a receptor potential (continued):
  - **Photoreceptors** – special sensory exteroceptors found <u>only</u> in eye; depolarize in response to *light*
  - **Nociceptors** – usually slowly adapting exteroceptors; depolarize in response to *noxious stimuli*

Capsaicin

- Hot peppers can make your mouth feel like it's on fire; result of chemical in peppers called **capsaicin**
- Capsaicin opens specific **ligand-gated ion channels** in *nociceptors* and triggers action potentials; causes CNS to perceive chemical as *painful*
- Repeated application of capsaicin to nociceptors seems to *desensitize* them; makes nociceptors <u>less</u> likely to generate receptor potentials in response to painful stimuli

Capsaicin

- Therefore, capsaicin may be applied as a topical cream to *relieve pain* of peripheral nerve disorders called **neuropathies**, **shingles**, a viral infection caused by chickenpox virus, and other conditions
- **Remember** – capsaicin doesn't do anything to *treat actual cause of pain*; it simply makes nociceptors less able to *relay painful stimuli to CNS*

Classification of Sensory Receptors

Classes of mechanoreceptors (**Figure 13.12**):

- **Merkel cell fibers** consist of a slowly adapting nerve ending surrounded by a capsule of **Merkel cells**
  - Found in *epidermal ridges* of integumentary system; primarily in skin of *hands* (especially *fingertips*)
  - Receptor potentials are generated by **mechanically gated ion channels**
  - Detect *discriminative touch stimuli* (object form and texture)

Classification of Sensory Receptors

Classes of mechanoreceptors (continued):

- **Tactile corpuscles** (**Meissner corpuscles**) – in *dermal papillae*; rapidly adapting tactile exteroceptors; transmit *discriminative touch stimuli*
- **Ruffini endings** (**bulbous corpuscles**) – spindle-shaped receptors found in *dermis*, *hypodermis*, and *ligaments*; slowly adapting receptors respond to *stretch* and *movement*

Classification of Sensory Receptors

Classes of mechanoreceptors (continued):

- **Lamellated corpuscles** (**Pacinian corpuscles**) – layered onion-shaped appearance; rapidly adapting receptors found deep within *dermis*; detect *high-frequency vibratory* and *deep pressure stimuli*; example of **Structure-Function Core Principle**
- Hair **follicle receptors** – free nerve endings surrounding base of *hair follicles* found in thin skin; not on palms and soles; respond to stimuli that cause hair to *bend*
- **Proprioceptors** – in musculoskeletal system; detect *movement* and *position* of a joint or body part

Classification of Sensory Receptors

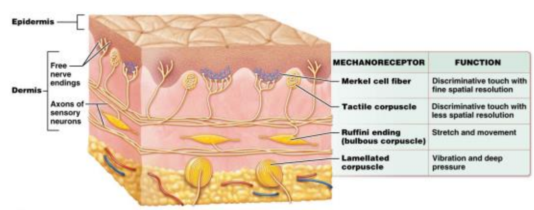


Figure 13.12 Mechanoreceptors in the skin.

Classification of Sensory Receptors

- **Types of thermoreceptors** – usually small knobs at end of free nerve endings in *skin*
  - "**Cold**" **receptors** – respond to temperatures between 10 °C and 40 °C (50–104 °F); in *superficial dermis*
  - "**Hot**" **receptors** – respond to temperatures between 32 °C and 48 °C (90–118 °F); *deep in dermis*
  - Temperatures outside these ranges are detected by *nociceptors*; reason extremes of temperature are interpreted as pain

Sensory Neurons

- Somatic sensory neurons are *pseudounipolar neurons* with three main components (**Figure 13.13**):
  - **Cell body** – cell bodies of spinal nerves are in *posterior (dorsal) root ganglion*, just lateral to spinal cord; cell bodies of cranial nerves are in *cranial nerve ganglia* in head and neck
  - **Peripheral process** – long axon that transmits action potentials from *source of stimulus* (receptor) to neuron's *central process*
  - **Central process** – exits *cell body* and travels through posterior root; enter *spinal cord* at posterior horn (or brainstem for cranial nerves) where they deliver their action potentials

Sensory Neurons

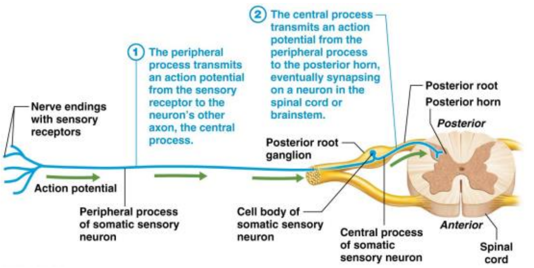


Figure 13.13 Somatic sensory neuron structure and function.

Sensory Neurons

- Sensory neurons are classified by two factors that determine *speed* with which peripheral axons conduct action potentials: diameter of *axon* and thickness of its *myelin sheath*
  - Large-diameter axons with thick myelin sheaths conduct *fastest* impulses; include axons that:
    - Conduct *proprioceptive* information to CNS
    - Convey discriminative and nondiscriminative *touch* information
  - Small-diameter axons with little myelin transmit action potentials *slowest*; include axons that carry *pain* and *temperature* stimuli to CNS

Sensory Neurons

- **Receptive fields** – areas served by a particular neuron; neuron with *more branches* innervate *larger* receptive fields (**Figure 13.14**)
  - Body regions whose primary function is *sensing environment* (fingertips) contain <u>many</u> neurons with *smaller* receptive fields
  - Body regions that are not as involved in sensing environment (skin of forearm) have <u>fewer</u> neurons with *larger* receptive fields
  - **Two-point discrimination threshold** – method for measuring relative size of receptive fields (**Figure 13.14b**)

Sensory Neurons

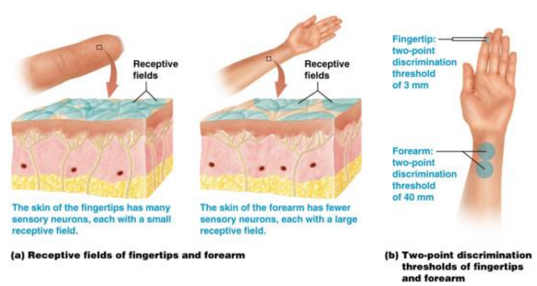


Figure 13.14 Receptive fields and two-point discrimination.

Dermatomes and Referred Pain

- Skin can be divided into different segments called **dermatomes** based on spinal nerve that supplies region with *somatic sensation*
  - Dermatomes can be combined to assemble a **dermatome map**; represents all (except first cervical spinal nerve) of sensory pathways to different parts of body (**Figure 13.15a**)
  - Dermatome maps can be used clinically to test *integrity of sensory pathway* to different parts of body

Dermatomes and Referred Pain

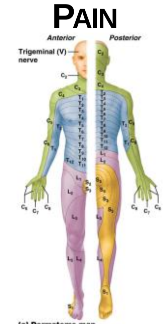


Figure 13.15a The dermatome map and referred pain.

Dermatomes and Referred Pain

- **Referred pain** – phenomenon whereby pain that originates in an *organ* is perceived as *cutaneous* pain
  - Occurs because many spinal nerves carry both *somatic* and *visceral neurons*, so visceral sensations travel along same *pathways* as do somatic sensations
  - Referred pain is generally located along *dermatome* for a particular *nerve*

Dermatomes and Referred Pain

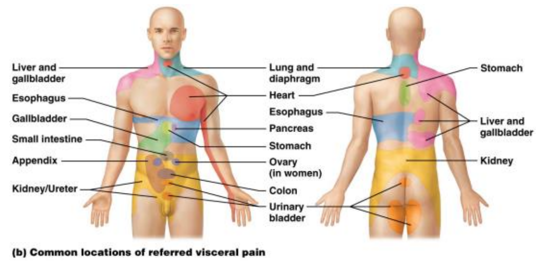


Figure 13.15b The dermatome map and referred pain.

The Big Picture of Detection and Interpretation of Somatic Sensation by the Nervous System

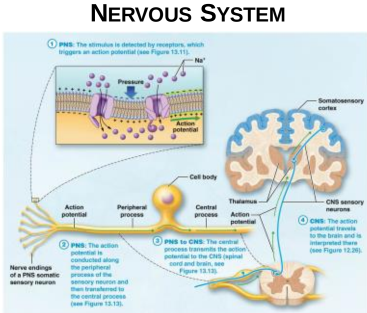


Figure 13.16 The Big Picture of Detection and Interpretation of Somatic Sensation by the Nervous System.

Module 13.5 Movement Part II: Role of the PNS in Movement

From CNS to PNS: Motor Output

- Muscular and nervous systems are inextricably linked to one another; skeletal muscle fibers are **voluntary**; contract only when stimulated to do so by a *somatic motor neuron*
  - **Upper motor neurons** – neurons of primary motor cortex make *decision* to move and *initiate* that movement; but not in contact with muscle fiber itself
  - **Lower motor neurons** – receive messages from upper motor neurons; in contact with skeletal muscle fibers; release acetylcholine onto muscle fibers to *initiate contraction*

The Role of Lower Motor Neurons

- **Lower motor neurons** – *multipolar neurons* whose cell bodies are in either anterior horn of spinal cord or brainstem; axons are in PNS
- **Motor neuron pools** – *groups* of lower motor neurons that innervate same muscle; found clustered in *anterior horn* of spinal cord
  - **Large motor neurons** – *majority* of neurons within pools; *stimulate skeletal muscle fibers* to contract by excitation-contraction mechanism
  - **Smaller motor neurons** – also found with these neuron pools; *innervate intrafusal fibers*; part of specialized **stretch receptors**

The Big Picture of Control of Movement by the Nervous System

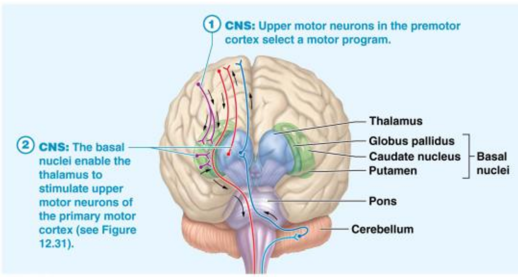


Figure 13.17 The Big Picture of Control of Movement by the Nervous System.

The Big Picture of Control of Movement by the Nervous System

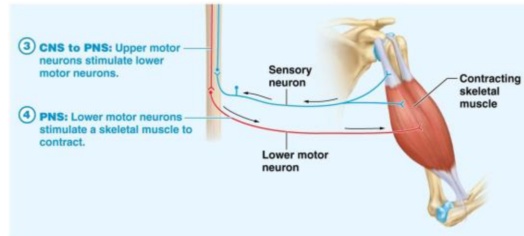


Figure 13.17 The Big Picture of Control of Movement by the Nervous System.

The Big Picture of Control of Movement by the Nervous System

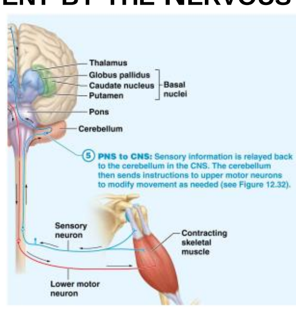


Figure 13.17 The Big Picture of Control of Movement by the Nervous System.

The Big Picture of Control of Movement by the Nervous System

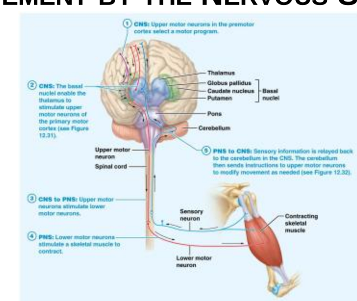


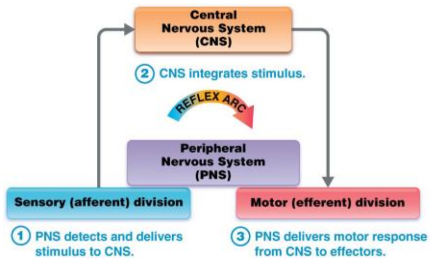
Figure 13.17 The Big Picture of Control of Movement by the Nervous System.

Module 13.6 Reflex Arcs: Integration of Sensory and Motor Functions

Reflex Arcs

- **Reflexes** – *programmed*, *automatic responses* to stimuli; occur in a three-step sequence of events called a **reflex arc**; usually *protective* negative feedback loops
  - Reflexes begin with a *sensory stimulus* and finish with a rapid *motor response*
  - *Neural integration* between sensory stimulus and motor response occurs in CNS, at *spinal cord* or *brainstem*

REFLEX ARCS



THE ROLE OF STRETCH RECEPTORS IN SKELETAL MUSCLES

Mechanoreceptors in muscles and tendons monitor muscle *length* and *force of contraction*; communicate this information to spinal cord, cerebellum, and cerebral cortex (**Figure 13.18**)

- **Muscle spindles** – tapered structures found scattered among regular contractile muscle fibers (**extrafusal muscle fibers**) (**Figure 13.18a**)
  - Between 2 and 12 *specialized* muscle fibers (**intrafusal muscle fibers**) are found within each muscle spindle

THE ROLE OF STRETCH RECEPTORS IN SKELETAL MUSCLES

- **Muscle spindles** – tapered structures found scattered among regular contractile muscle fibers (**extrafusal muscle fibers**) (**Figure 13.18a**) (continued):
  - Intrafusal fibers have contractile filaments composed of actin and myosin at their *poles*; innervated by motor neurons
  - Contractile filaments are absent in the *central area* of intrafusal fibers

THE ROLE OF STRETCH RECEPTORS IN SKELETAL MUSCLES

- Two structural and functional classes of *sensory neurons* innervate intrafusal fibers:
  - **Primary afferents** respond to *stretch* when it is first initiated
  - **Secondary afferents** respond to both *static length* of a muscle and *position* of a limb

THE ROLE OF STRETCH RECEPTORS IN SKELETAL MUSCLES

- **Golgi tendon organs** – *mechanoreceptors* located within tendons near *muscle-tendon junction*; have following features (**Figure 13.18b**):
  - Monitor *tension* generated by a muscle contraction
  - Consist of an *encapsulated bundle of collagen fibers* attached to about 20 *extrafusal muscle fibers*
  - Contain a single somatic sensory axon that fires *more rapidly* as *greater tension* is generated with each contraction; information is sent to CNS

THE ROLE OF STRETCH RECEPTORS IN SKELETAL MUSCLES

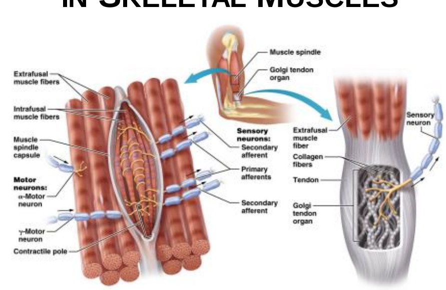


Figure 13.18 Muscle spindles and Golgi tendon organs.

TYPES OF REFLEXES

- Reflexes can be classified by at least two criteria (**Figures 13.19**, **13.20**):
  - *Number of synapses* that occur between neurons involved in arc
  - *Type of organ* in which reflex takes place, either visceral or somatic
- Simplest reflex arcs (**monosynaptic reflexes**) involve only a single synapse within spinal cord between a sensory and motor neuron; more complicated types of reflex arcs (**polysynaptic reflexes**) involve multiple synapses

TYPES OF REFLEXES

- **Simple stretch reflex**
  - Body's reflexive response to stretching of muscle to shorten it back to within its "*set*" *optimal length*
  - **Patellar** (**knee-jerk**) **reflex** and **jaw-jerk reflex** are examples of simple stretch reflexes

TYPES OF REFLEXES

- **Simple stretch reflex** (continued):
  - Steps in a simple stretch reflex in a spinal nerve (**Figure 13.19**):
    - External force *stretches* muscle
    - Muscle spindles *detect* stretch; primary and secondary afferents *transmit* an action potential to spinal cord
    - In spinal cord, sensory afferents *synapse* on motor neurons and *trigger* an action potential
    - Motor neurons *stimulate* muscle to contract and it returns to its *optimal length*

TYPES OF REFLEXES

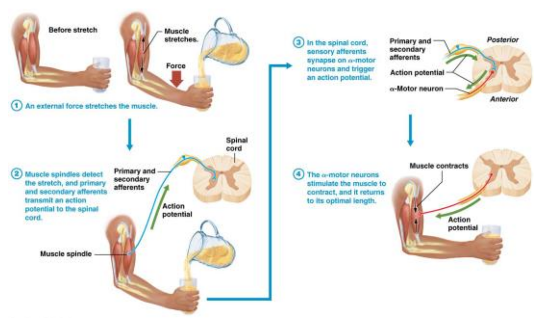


Figure 13.19 A simple stretch reflex.

TYPES OF REFLEXES

- **Golgi tendon reflexes** – *polysynaptic* reflexes; protect muscles and tendons from damaging forces
  - Causes muscle *relaxation*; opposite of simple stretch reflex action
  - When tension in muscle and tendon *increases dramatically*, Golgi tendon organs signal spinal cord and cerebellum
  - Motor neurons innervating muscle are *inhibited* while antagonist muscles are simultaneously *activated*

TYPES OF REFLEXES

- **Flexion** (**withdrawal**) **and crossed-extension spinal reflexes** (**Figure 13.20**):
  - **Flexion or withdrawal reflex** involves rapidly conducting nociceptive afferents and multiple synapses in spinal cord; act to *withdraw limb* from painful stimuli (**Figure 13.20a**)
  - **Crossed-extension reflex** occurs simultaneously on opposite side of body for *balance* and *postural support* while other limb is withdrawn from a painful stimulus (**Figure 13.20b**)

Types of Reflexes

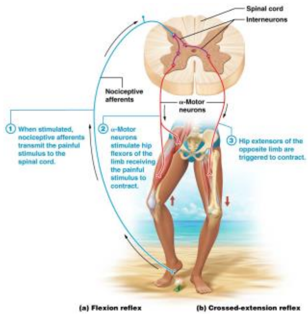


Figure 13.20 The flexion and crossed-extension reflexes.

Types of Reflexes

- **Cranial nerve reflexes** – *polysynaptic* reflex arcs that involve *cranial nerves*
  - **Gag reflex** – triggered when visceral sensory nerve endings of glossopharyngeal nerve in *posterior throat* are stimulated
  - **Corneal blink reflex** – triggered when a stimulus reaches somatic sensory receptors of trigeminal nerve in thin *outer covering of eye* (**cornea**); something contacts eye leading to a blink response

Sensory and Motor Neuron Disorders

- Disorders that impact sensory and motor neurons of PNS are collectively called **peripheral neuropathies** (**Figure 13.21**)
  - **Sensory neuron disorders** – severity depends on <u>which</u> spinal or cranial nerve is involved
  - **Lower motor neuron disorders** – usually result from injury of a spinal or cranial nerve or injury of lower motor neuron cell body; <u>prevent</u> motor nerve from *initiating* skeletal muscle contraction

Sensory and Motor Neuron Disorders

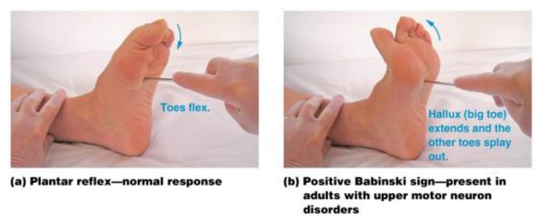


Figure 13.21 The Babinski sign.

Sensory and Motor Neuron Disorders

- **Upper motor neuron disorders** – impact neurons of CNS, so <u>not</u> considered *peripheral* neuropathies (**Figure 13.21**)
  - Can result from damage or disease <u>anywhere</u> along pathways from motor cortices to spinal cord
  - Body's initial response to upper motor neuron damage is **spinal shock**, characterized by paralysis; believed to result from "shock" experienced by spinal cord circuits when input from upper motor neurons is *removed*

Sensory and Motor Neuron Disorders

- **Upper motor neuron disorders** (continued):
  - After a few days shock wears off and **spasticity** often develops; characterized by an increase in *stretch reflexes*, an increase in *muscle tone*, and a phenomenon called **clonus** (alternating contraction/relaxation of stretched muscle)
  - Spasticity is likely due to a *loss of normal inhibition* mediated by upper motor neurons

Sensory and Motor Neuron Disorders

- **Upper motor neuron disorders** (continued):
  - **Babinski sign** also develops; elicited by stroking bottom of foot:
    - Healthy adult will *flex toes*, a response known as **plantar reflex** (**Figure 13.21a**)
    - Patient with an upper motor neuron disorder will *extend hallux* (*big toe*) *and splay out other toes* (**Figure 13.21b**)
  - A positive Babinski sign is often present in *infants up to 18 months old* and does <u>not</u> signify pathology; same response in an adult is <u>always</u> considered *abnormal*

Amyotrophic Lateral Sclerosis

- **Amyotrophic lateral sclerosis** (**ALS**), also known as **Lou Gehrig's disease**, involves *degeneration* of cell bodies of *motor neurons* in anterior horn of spinal cord as well as upper motor neurons in cerebral cortex; cause of degeneration is *unknown* at present; many factors likely play a role
- Most common early feature of disease is *muscle weakness*, particularly in distal muscles of limbs and hands; over time weakness spreads to other muscle groups; upper motor neuron symptoms also develop

Amyotrophic Lateral Sclerosis

- Death typically results within 5 years of disease's onset; in most forms of ALS, cognitive functions are spared; patient is *fully aware* of effects and complications of disease
- Although intensive research efforts are ongoing, at this time there is *no cure or treatment* that prevents disease progression