SENSORY PHYSIOLOGY (I)

SENSORY RECEPTORS AND SENSATIONS

Sensory receptors are specialized to detect certain types of stimuli. **Exteroceptors** are sensory receptors that detect stimuli from outside the body. Stimuli that result in taste, smell, vision, hearing, and equilibrium all originate outside the body. **Interoceptors** receive stimuli from inside the body. We have had an opportunity in other chapters to mention **pressoreceptors** that respond to changes in blood pressure, **osmoreceptors** that detect changes in blood volume, and **chemoreceptors** that monitor the pH of the blood.

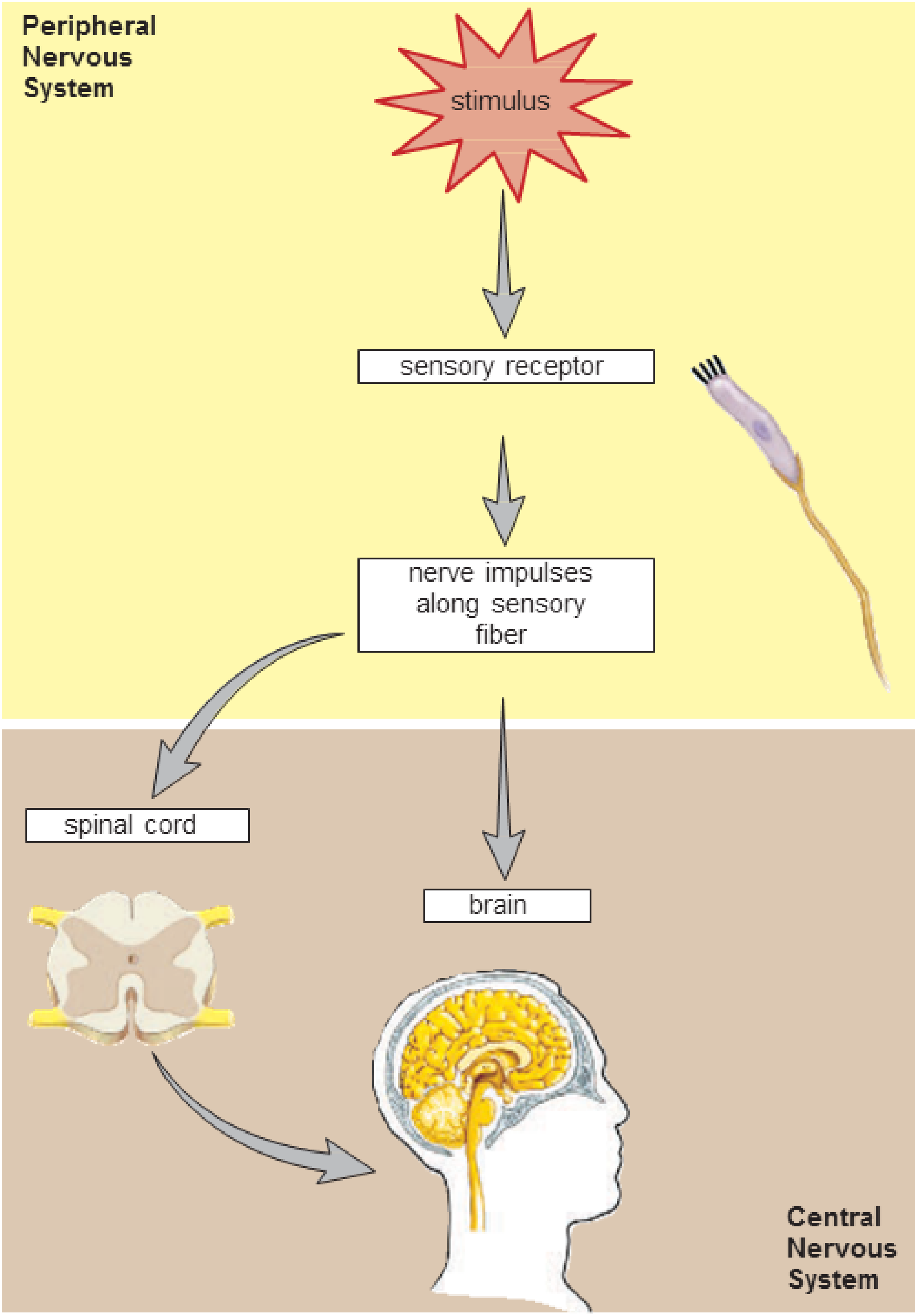
EXTEROCEPTORS

Sensory Receptor	Stimulus	Category	Sense	Sensory Organ
Taste cells	Chemicals	Chemoreceptor	Taste	Taste buds
Olfactory cells	Chemicals	Chemoreceptor	Smell	Olfactory epithelium
Rod cells and cone cells in retina	Light rays	Photoreceptor	Vision	Eye
Hair cells in spiral organ	Sound waves	Mechanoreceptor	Hearing	Ear
Hair cells in semi-circular canals	Motion	Mechanoreceptor	Rotational equilibrium	Ear
Hair cells in vestibule	Gravity	Mechanoreceptor	Gravitational equilibrium	Ear

TYPES OF SENSORY RECEPTORS

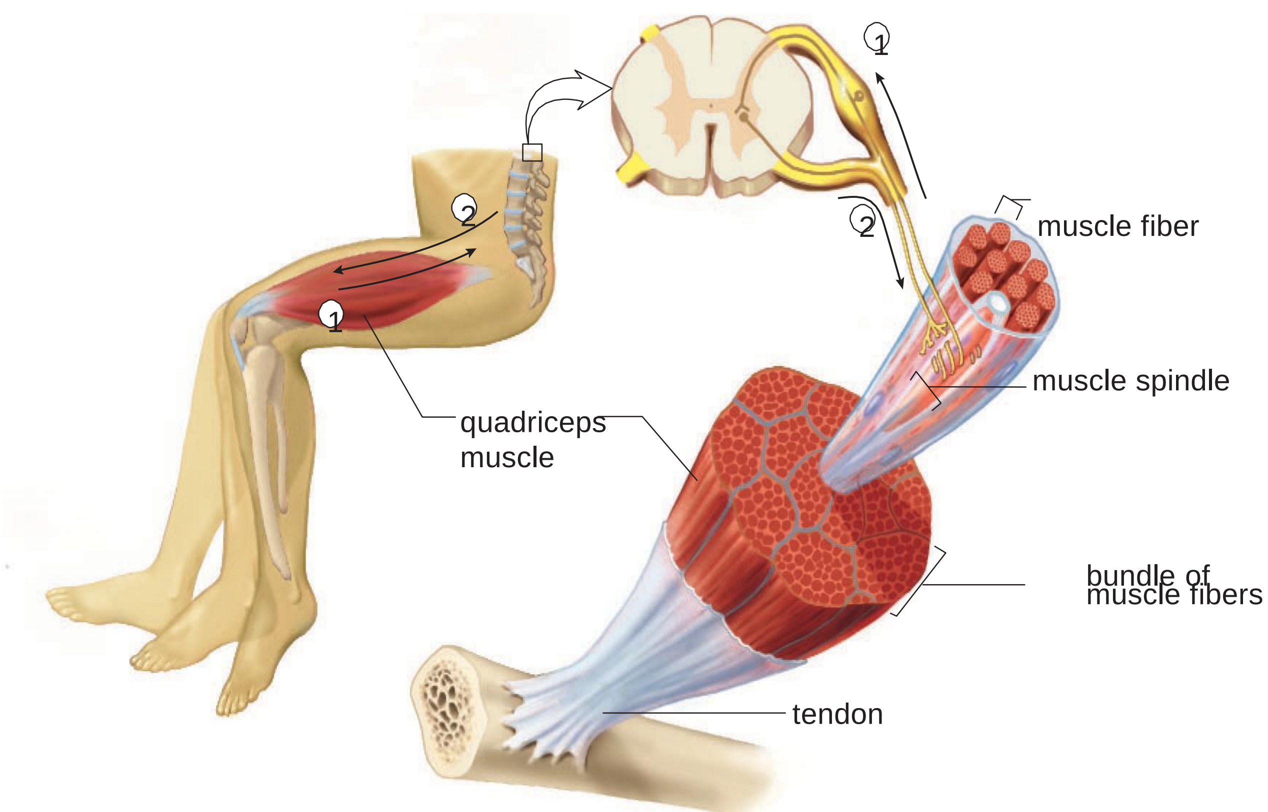
- Sensory receptors in humans can be classified into just four categories: **chemoreceptors**, **photoreceptors**, **mechanoreceptors**, and **thermoreceptors**.
- **Chemoreceptors** respond to chemical substances in the immediate vicinity. Taste and smell are dependent on this type of sensory receptor, but certain chemoreceptors in various other organs are sensitive to internal conditions. Chemoreceptors that monitor blood pH are located in the carotid arteries and aorta. If the pH lowers, the breathing rate increases. As more carbon dioxide is expired, the blood pH rises.
- **Pain receptors (nociceptors)** are a type of chemoreceptor. They are naked dendrites that respond to chemicals released by damaged tissues. Pain receptors are protective because they alert us to possible danger.
- **Photoreceptors** respond to light energy. Our eyes contain photoreceptors that are sensitive to light rays and thereby provide us with a sense of vision. Stimulation of the photoreceptors known as rod cells results in black and white vision, while stimulation of the photoreceptors known as cone cells results in color vision.
- **Mechanoreceptors** are stimulated by mechanical forces, which most often result in pressure of some sort. When we hear, airborne sound waves are converted to water-borne pressure waves that can be detected by mechanoreceptors in the inner ear. Similarly, mechanoreceptors are responding to water-borne pressure waves when we detect changes in gravity and motion, helping us keep our balance. These receptors are in the vestibule and semicircular canals of the inner ear, respectively. The sense of touch is dependent on pressure receptors that are sensitive to either strong or slight pressures.
- **Pressoreceptors** located in certain arteries detect changes in blood pressure, and stretch receptors in the lungs detect the degree of lung inflation.
- **Proprioceptors**, which respond to the stretching of muscle fibers, tendons, joints, and ligaments, make us aware of the position of our limbs.
- **Thermoreceptors** located in the hypothalamus and skin are stimulated by changes in temperature. Those that respond when temperatures rise are called warmth receptors, and those that respond when temperatures lower are called cold receptors.

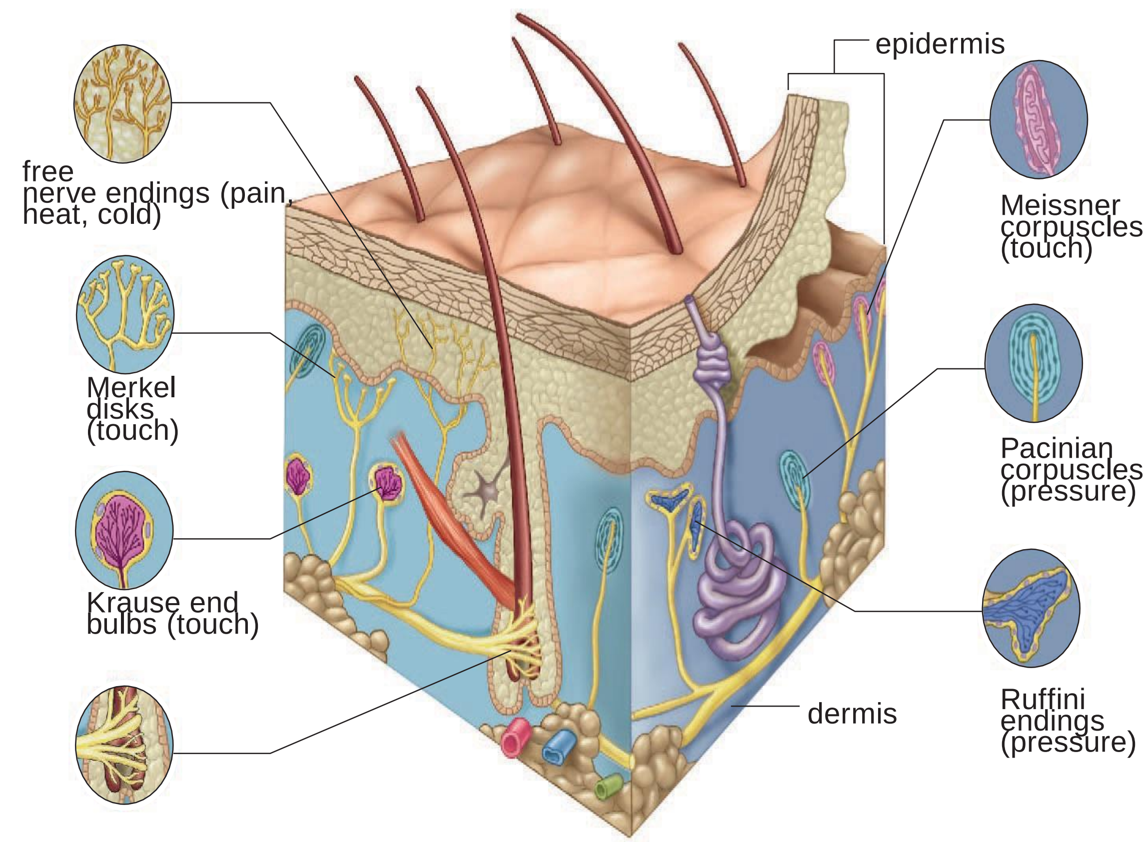
HOW SENSATION OCCURS



- The stimulus is received by a sensory receptor, which generates nerve impulses (action potentials). Nerve impulses are conducted to the CNS by sensory nerve fibers within the PNS, and only those impulses that reach the cerebral cortex result in sensation and perception.
- Although sensory receptors simply initiate nerve impulses, we have different senses. The brain is responsible for sensation and perception. Nerve impulses that begin in the optic nerve eventually reach the visual areas of the cerebral cortex and, thereafter, we see objects. Nerve impulses that begin in the auditory nerve eventually reach the auditory areas of the cerebral cortex and, thereafter, we hear sounds.
- Before sensory receptors initiate nerve impulses, they carry out integration, the summing up of signals. One type of integration is called sensory adaptation, a decrease in response to a stimulus.

PROPRIOCEPTORS AND CUTANEOUS RECEPTORS





MUSCLE SPINDLE

When a muscle is stretched, a muscle spindle sends sensory nerve impulses to the spinal cord. Motor nerve impulses from the spinal cord result in muscle fiber contraction so that muscle tone is maintained.

- Sensory receptors in the human skin are sensitive to touch, pressure, pain, and temperature (warmth and cold).
- It appears that the receptors of the skin are somewhat, but not completely, specialized.
- Pain receptors, also called nociceptors, are present in the skin and internal organs.

PAIN RECEPTORS

- Pain receptors, also called nociceptors, are present in the skin and internal organs.
- Like the skin, many internal organs have pain receptors, also called nociceptors. Pain receptors are sensitive to extremes in temperature or pressure and to chemicals released by damaged tissues. When inflammation occurs, cells release chemicals that stimulate pain receptors. Aspirin and ibuprofen reduce pain by inhibiting the synthesis of one class of these chemicals.
- Sometimes, stimulation of internal pain receptors is felt as pain from the skin as well as internal organs. This is called referred pain. Some internal organs have a referred pain relationship with areas located in the skin of the back, groin, and abdomen; pain from the heart is felt in the left shoulder and arm. This most likely happens when nerve impulses from the pain receptors of internal organs travel to the spinal cord and synapse with neurons also receiving impulses from the skin.
- Pain is a sensation characterized by a group of unpleasant perceptual and emotional experiences. There are two types of pain sensation: (1) sharp, well-localized, pricking, or cutting pain resulting from rapidly conducted action potentials and (2) diffuse, burning, or aching pain resulting from action potentials that are propagated more slowly.
- Superficial pain sensations in the skin are highly localized as a result of the simultaneous stimulation of pain receptors and tactile receptors, which help to localize the source of the pain stimuli. Deep or visceral pain sensations are not highly localized because of the absence of tactile receptors in the deeper structures. Visceral pain stimuli are normally perceived as diffuse pain.
- Action potentials from pain receptors in local areas of the body can be suppressed by chemical anesthetics injected near a sensory nerve and result in reduced pain sensation. This treatment is called local anesthesia. Pain sensations can also be suppressed if consciousness is inhibited by chemical anesthetics that affect the reticular formation. This treatment is called general anesthesia.
- Pain sensations can also be influenced by inherent control systems. Afferent axons from tactile receptors in the skin have collateral branches that synapse with neurons in the dorsal horn of the spinal cord. Those neurons, in turn, synapse with and inhibit the neurons in the dorsal horn that give rise to the lateral spinothalamic tract. Rubbing the skin in the area of an injury stimulates the tactile receptors, which send action potentials along the afferent axons to the spinal cord.
- The descending neurons synapse with and inhibit neurons in the dorsal horn that give rise to the lateral spinothalamic tract. Vigorous mental or physical activity increases the rate of action potentials in neurons of the dorsal column and can reduce the sensation of pain.

SENSES OF TASTE AND SMELL

- The receptors for taste are found in taste buds located primarily on the tongue. Many lie along the walls of the papillae, the small elevations on the tongue that are visible to the naked eye. Isolated ones are also present on the hard palate, the pharynx, and the epiglottis.
- Taste buds are embedded in tongue epithelium and open at a taste pore. They have supporting cells and a number of elongated taste cells that end in microvilli. The microvilli bear receptor proteins for certain molecules. When these molecules bind to receptor proteins, nerve impulses are generated in associated sensory nerve fibers. These nerve impulses go to the brain, including cortical areas, which interpret them as tastes.
- There are four primary types of taste (sweet, sour, salty, bitter), and taste buds for each are concentrated on the tongue in particular regions. Sweet receptors are most plentiful near the tip of the tongue. Sour receptors occur primarily along the margins of the tongue. Salty receptors are most common on the tip and upper front portion of the tongue. Bitter receptors are located toward the back of the tongue. Actually, the response of taste buds can result in a range of sweet, sour, salty, and bitter tastes. The brain appears to survey the overall pattern of incoming sensory impulses and to take a “weighted average” of their taste messages as the perceived taste.
- The sense of smell is dependent on olfactory cells located within olfactory epithelium high in the roof of the nasal cavity. Olfactory cells are modified neurons. Each cell ends in a tuft of about five olfactory cilia, which bear receptor proteins for odor molecules. Each olfactory cell has only one out of 1,000 different types of receptor proteins. Nerve fibers from like olfactory cells lead to the same neuron in the olfactory bulb, an extension of the brain. An odor contains many odor molecules, which activate a characteristic combination of receptor proteins. A rose might stimulate olfactory cells, designated by purple and green, while a daffodil might stimulate a different combination. An odor’s signature in the olfactory bulb is determined by which neurons are stimulated. When the neurons communicate this information via the olfactory tract to the olfactory areas of the cerebral cortex, we know we have smelled a rose or a daffodil.

SENSE OF VISION

Vision requires the work of the eyes and the brain. As we shall see, much processing of stimuli occurs in the eyes before nerve impulses are sent to the brain. Still, researchers estimate that at least a third of the cerebral cortex takes part in processing visual information.

Table 14.2 **Functions of the Parts of the Eye**

Part	Function
Sclera	Protects and supports eyeball
Cornea	Refracts light rays
Choroid	Absorbs stray light
Retina	Contains sensory receptors for sight
Rods	Make black-and-white vision possible
Cones	Make color vision possible
Fovea centralis	Makes acute vision possible
Lens	Refracts and focuses light rays
Ciliary body	Holds lens in place, accommodation
Iris	Regulates light entrance
Pupil	Admits light
Humors	Transmit light rays and support eyeball
Optic nerve	Transmits impulse to brain

INTEGRATION OF VISUAL SIGNALS IN THE BRAIN

- Sensory fibers from ganglion cells assemble to form the optic nerves. At the X-shaped optic chiasma, fibers from the right half of each retina converge and continue on together in the right optic tract, and fibers from the left half of each retina converge and continue on together in the left optic tract.
- The image is split because the left optic tract carries information about the right portion of the visual field, and the right optic tract carries information about the left portion of the visual field.
- The optic tracts sweep around the hypothalamus, and most fibers synapse with neurons in nuclei (masses of neuron cell bodies) of the thalamus. Axons from the thalamic nuclei form optic radiations that take nerve impulses to the primary visual areas of the cerebral cortex.
- Since each primary visual area receives information regarding only half the visual field, these areas must eventually share information to form a unified image. Also, the inverted and reversed image must be righted in the brain for us to correctly perceive the visual field.
- The most surprising finding has been that the brain has a further way of taking the field apart. Each primary visual area of the cerebral cortex acts like a post office, parceling out information regarding color, form, motion, and possibly other attributes to different portions of the adjoining visual association area. Therefore, the brain has taken the field apart even though we see a unified visual field. The cerebral cortex is believed to rebuild the visual field and give us an understanding of it at the same time.

SENSE OF HEARING

- Hearing is dependent on the ear, the cochlear nerve, and the auditory areas of the cerebral cortex. The ear is divided into three parts: outer, middle, and inner. The outer ear consists of the pinna and the auditory canal, which direct sound waves to the middle ear. The middle ear begins with the tympanic membrane and contains the ossicles (malleus, incus, and stapes). The malleus is attached to the tympanic membrane, and the stapes is attached to the oval window, which is covered by a membrane. The inner ear contains the cochlea and the semicircular canals, plus the utricle and the saccule.

- Hearing begins when the outer and middle portions of the ear convey and amplify the sound waves that strike the oval window. Its vibrations set up pressure waves within the cochlea, which contains the spiral organ, consisting of hair cells whose stereocilia are embedded within the tectorial membrane. When the stereocilia of the hair cells bend, nerve impulses begin in the cochlear nerve and are carried to the brain.

SENSE OF EQUILIBRIUM

- The ear also contains mechanoreceptors for our sense of equilibrium. **Rotational equilibrium** is dependent on the stimulation of hair cells within the ampullae of the semicircular canals. **Gravitational equilibrium** relies on the stimulation of hair cells within the utricle and the saccule.

- **Rotational equilibrium** involves the semicircular canals, which are arranged so that there is one in each dimension of space. The base of each of the three canals, called the ampulla, is slightly enlarged. Little hair cells, whose stereocilia are embedded within a gelatinous material called a cupula, are found within the ampullae. Because there are three semicircular canals, each ampulla responds to head rotation in a different plane of space. As fluid within a semicircular canal flows over and displaces a cupula, the stereocilia of the hair cells bend, and the pattern of impulses carried by the vestibular nerve to the brain changes. Continuous movement of fluid in the semicircular canals causes one form of motion sickness.

- **Gravitational equilibrium** depends on the utricle and saccule, two membranous sacs located in the vestibule. Both of these sacs contain little hair cells, whose stereocilia are embedded within a gelatinous material called an otolithic membrane. Calcium carbonate granules, or otoliths, rest on this membrane. The utricle is especially sensitive to horizontal movements and the bending of the head, while the saccule responds best to vertical (up-down) movements. When the body is still, the otoliths in the utricle and the saccule rest on the otolithic membrane above the hair cells. When the head bends or the body moves in the horizontal and vertical planes, the otoliths are displaced and the otolithic membrane sags, bending the stereocilia of the hair cells beneath. If the stereocilia move toward the kinocilium, the largest stereocilium, nerve impulses in the vestibular nerve increase. If the stereocilia move away from the kinocilium, nerve impulses in the vestibular nerve decrease. These data tell the brain the direction of the movement of the head.

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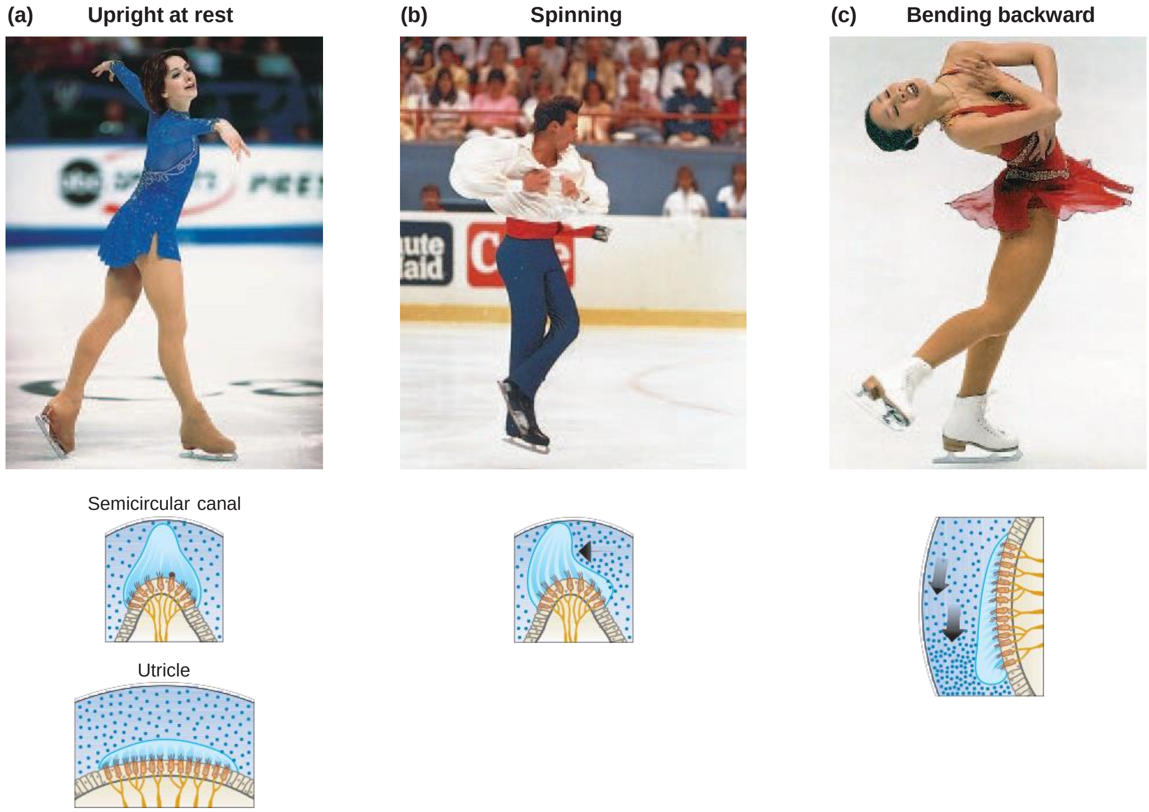
VESTIBULAR INFORMATION

VESTIBULAR INFORMATION IS USED IN THREE WAYS

- One is to control the eye muscles so that, in spite of changes in head position, the eyes can remain fixed on the same point. Nystagmus is a large, jerky, back-and-forth movement of the eyes that can occur in response to unusual vestibular input in normal people but can also be a pathological sign.
- The second use of vestibular information is in reflex mechanisms for maintaining upright posture. The vestibular apparatus plays a role in the support of the head during movement, orientation of the head in space, and reflexes accompanying locomotion. Very few postural reflexes, however, depend exclusively on input from the vestibular system despite the fact that the vestibular organs are sometimes called the sense organs of balance.
- The third use of vestibular information is in providing conscious awareness of the position and acceleration of the body, perception of the space surrounding the body, and memory of spatial information. Information about hair cell stimulation is relayed from the vestibular apparatus to nuclei within the brainstem via the vestibular branch of cranial nerve VIII (the same cranial nerve that carries acoustic information). It is transmitted via a multineuronal pathway through the thalamus to a system of vestibular centers in the parietal lobe. Descending projections also are sent from the brainstem nuclei to the spinal cord to influence postural reflexes. Vestibular information is integrated with information from the joints, tendons, and skin, leading to the sense of posture (proprioception) and movement.

Head Position



The semicircular canals (a) detect rotational and angular movements of the head that cause movement of the fluid within the canal. the utricle (b) and saccule detect information about linear movements relative to gravity.

REVIEW QUESTIONS

- What are the four categories of sensory receptors in the human body?
- Explain sensation, from the reception of stimuli to the passage of nerve impulses to the brain.
- Explain how muscle spindles are involved in proprioception.
- What are the cutaneous senses? What causes pain, and what is referred pain?
- Describe the anatomy of the ear and how we hear.
- Describe the roles of the semicircular canals, the utricle, and the saccule in equilibrium.
- Explain ways of using vestibular information in everyday life.