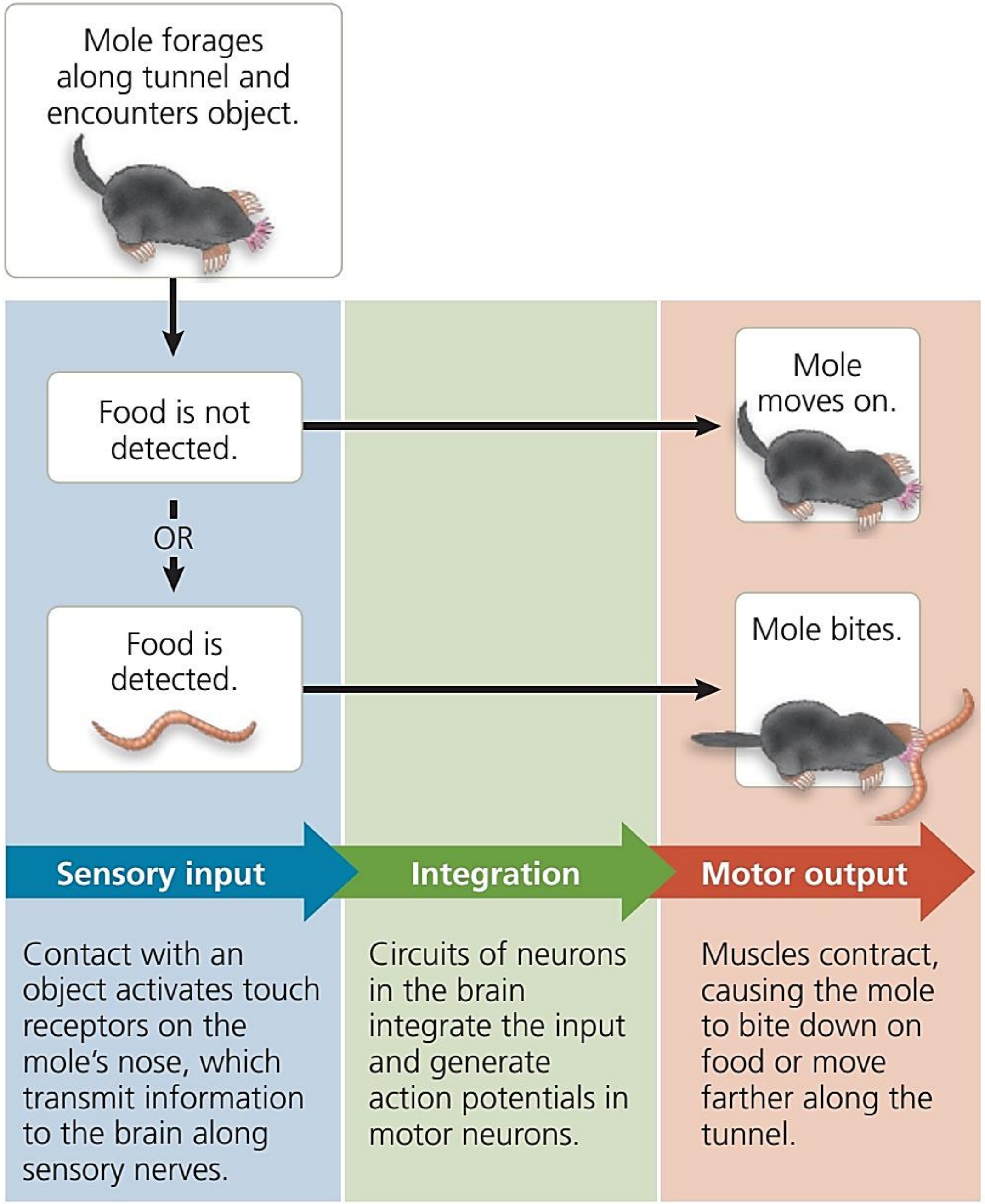
Sensory receptors transduce stimulus energy and transmit signals to the central nervous system

All sensory processes begin with stimuli, and all stimuli represent forms of energy. A sensory receptor converts stimulus energy to a change in membrane potential, thereby regulating the output of action potentials to the central nervous system (CNS). Decoding of this information within the CNS results in sensation. When a stimulus is received and processed by the nervous system, a motor response may be generated.

Four basic functions common to sensory pathways: **sensory reception**, **transduction**, **transmission**, and **perception**.

▼ **Figure 50.2 A simple response pathway: foraging by a star-nosed mole.**



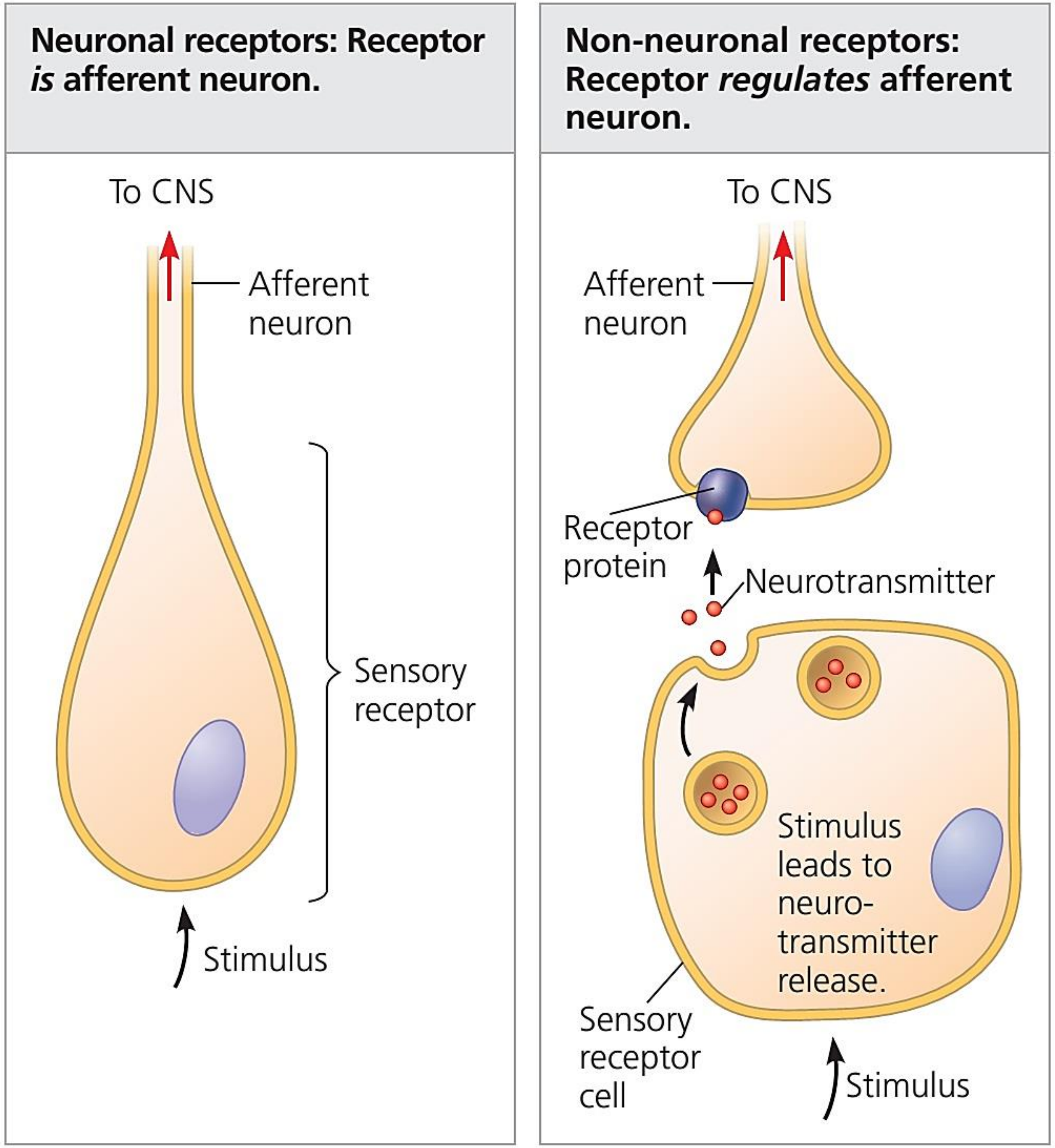
Sensory Reception and Transduction

A sensory pathway begins with **sensory reception**, the detection of a stimulus by specialized sensory cells. Each sensory cell is either a neuron or a cell that regulates a neuron (Figure 50.3). Some sensory cells exist singly; others are collected in sensory organs.

The term sensory receptor describes a sensory cell or organ, as well as the subcellular structure that detects stimuli. Some sensory receptors respond to stimuli from within the body, such as blood pressure and body position. Other receptors detect stimuli from outside the body, such as heat, light, pressure, or chemicals. Some of these receptors are sensitive to the smallest possible unit of stimulus. Most light receptors, for example, can detect a single quantum (photon) of light.

Although animals use a range of sensory receptors to detect widely varying stimuli, the effect in all cases is to open or close ion channels. The resulting change in the flow of ions across the membrane alters the **membrane potential**. The change in membrane potential is called a **receptor potential**, and conversion of the stimulus to a receptor potential is known as **sensory transduction**. Note that receptor potentials are graded potentials: Their magnitude varies with the strength of the stimulus.

▼ Figure 50.3 Neuronal and non-neuronal sensory receptors.



Types of Sensory Receptors

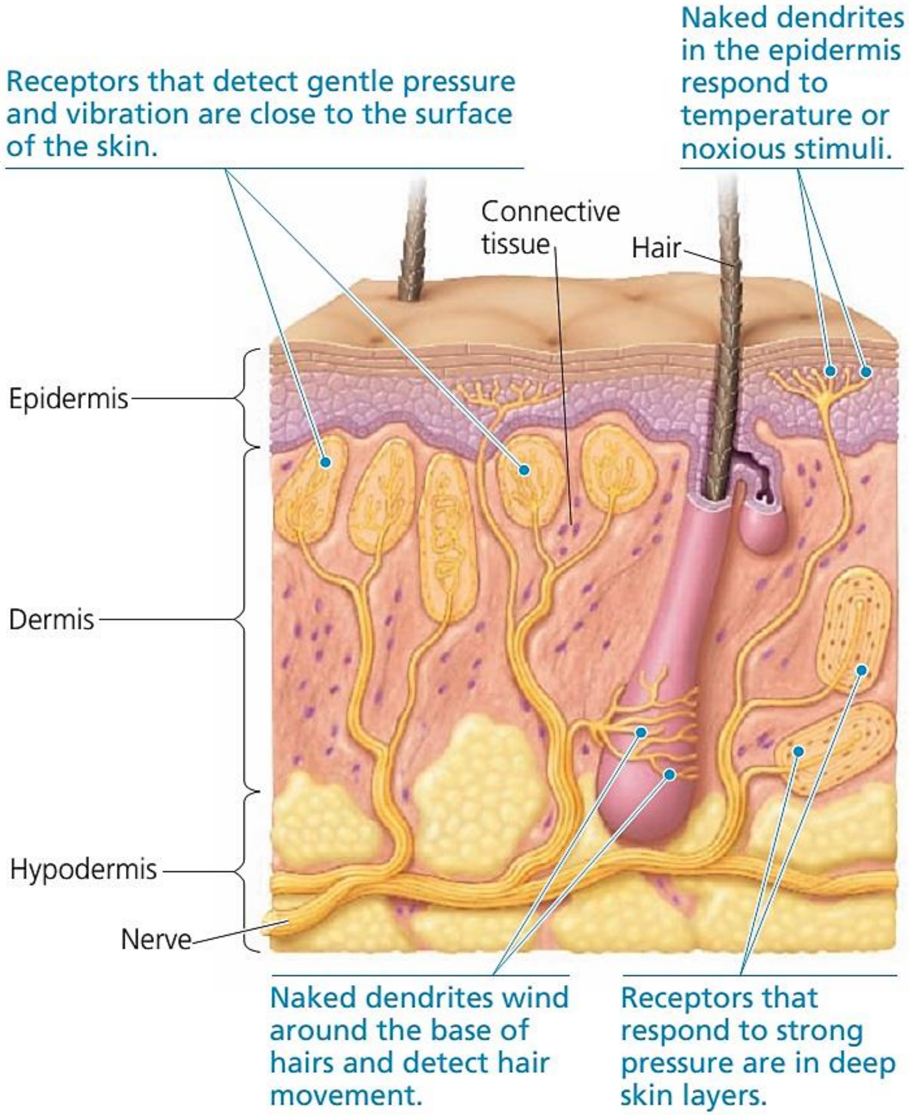
Sensory receptors fall into five categories based on the nature of the stimuli they transduce: **mechanoreceptors**, **chemoreceptors**, **electromagnetic receptors**, **thermoreceptors**, and **pain receptors**.

Mechanoreceptors

Our senses of hearing and balance, as well as our responses to pressure, touch, stretch, and motion, rely on sensory receptors called mechanoreceptors, which sense physical deformation caused by forms of mechanical energy. Mechanoreceptors typically consist of ion channels that are linked to structures that extend outside the cell, such as “hairs” (cilia), and also anchored to internal cell structures, such as the cytoskeleton. Bending or stretching of the external structure generates tension that alters ion channel permeability. This change in turn alters the membrane potential, resulting in a receptor potential—a depolarization or hyperpolarization.

Stretch receptors in vertebrates are dendrites of sensory neurons that spiral around the middle of certain small skeletal muscle fibers. When the muscle fibers are stretched, the sensory neurons depolarize, triggering nerve impulses that reach the spinal cord, activate motor neurons, and generate a reflex response.

Mechanoreceptors that are the dendrites of sensory neurons are also responsible for the mammalian sense of touch. **Touch receptors** are often embedded in layers of connective tissue. The structure of the connective tissue and the location of the receptors dramatically affect the type of mechanical energy (**light touch**, **vibration**, or **strong pressure**) that best stimulates them. Receptors that detect a light touch or vibration are close to the surface of the skin; they transduce very slight inputs of mechanical energy into receptor potentials. Receptors that respond to stronger pressure and vibrations are in deep skin layers.

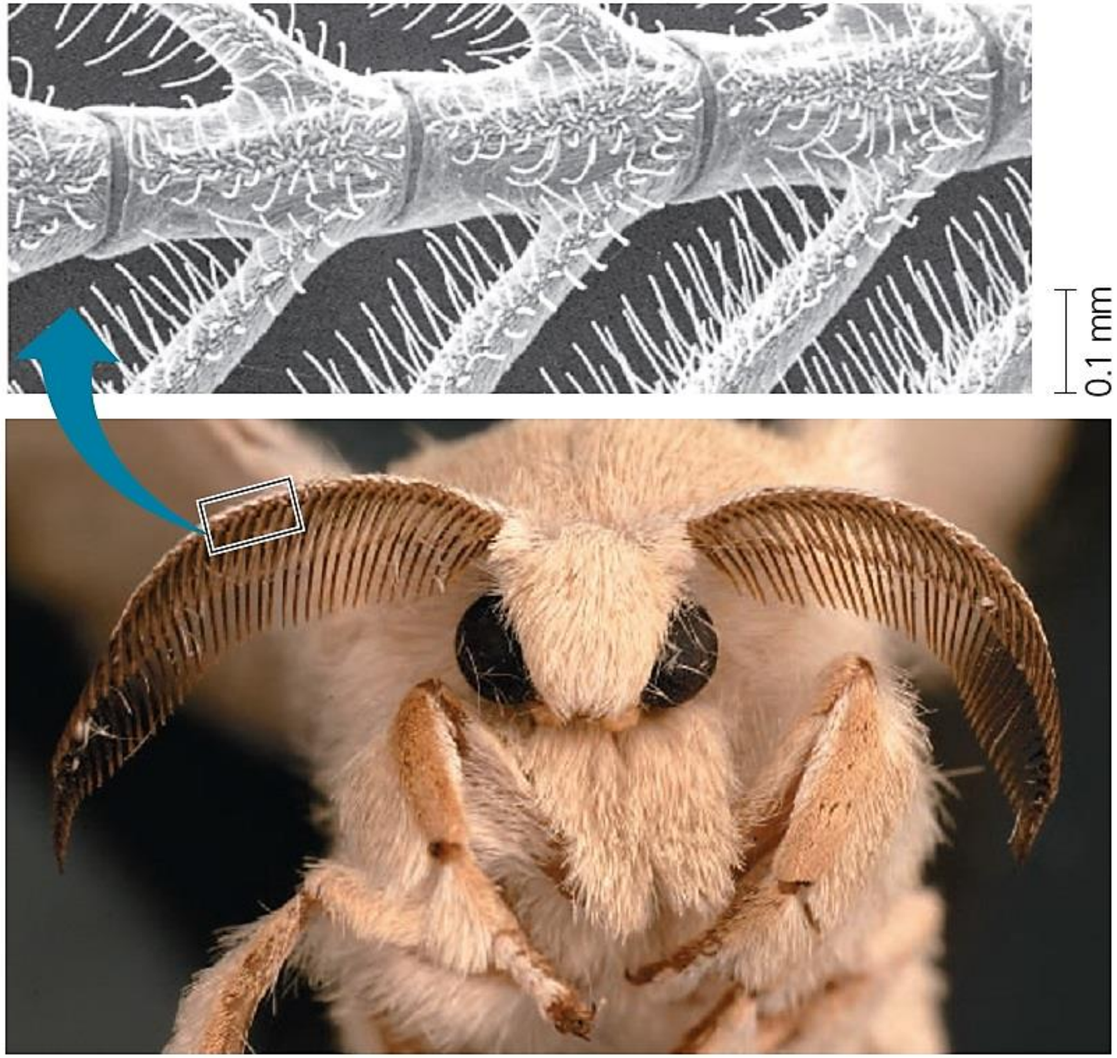


▼ **Figure 50.5 Sensory receptors in human skin.** Most receptors in the dermis are encapsulated by connective tissue. Receptors in the epidermis are naked dendrites, as are hair movement receptors that wind around the base of hairs in the dermis.

Chemoreceptors

Chemoreceptors that monitor the internal environment fall into two broad categories. Some transmit information about overall solute concentration. For example, osmoreceptors in the mammalian brain detect changes in the total solute concentration of the blood and stimulate thirst when osmolarity increases. Other chemoreceptors respond to specific molecules in body fluids, including glucose, oxygen, carbon dioxide, and amino acids.

Animals also use chemoreceptors to detect stimuli in their diet and in the environment they occupy. The antennae of the male silkworm moth contain two of the most sensitive and specific chemoreceptors known; these receptors can detect components of the sex pheromone released by a female moth several kilometers away. For pheromones and other molecules detected by chemoreceptors, the stimulus molecule binds to the specific receptor on the membrane of the sensory cell and initiates changes in ion permeability.



▼ **Figure 50.6 Chemoreceptors in an insect.** The antennae of the male silkworm moth *Bombyx mori* are covered with sensory hairs, visible in the SEM enlargement. The hairs have chemoreceptors that are highly sensitive to the sex pheromone released by the female.

Electromagnetic Receptors

An electromagnetic receptor detects a form of electromagnetic energy, such as light, electricity, and magnetism. For instance, the platypus has electroreceptors on its bill that can detect the electric field generated by the muscles of crustaceans, small fishes, and other prey. In a few cases, the animal detecting the stimulus is also its source: Some fishes generate electric currents and then use electroreceptors to locate prey or other objects that disturb those currents.

Many animals can use Earth's magnetic field lines to orient themselves as they migrate. In 2015, researchers identified a pair of proteins that appear to act as a sensor for the Earth's magnetic field in many animals that can orient to it, including monarch butterflies, pigeons, and minke whales. One of these proteins binds iron; the other is a receptor that is sensitive to electromagnetic radiation.

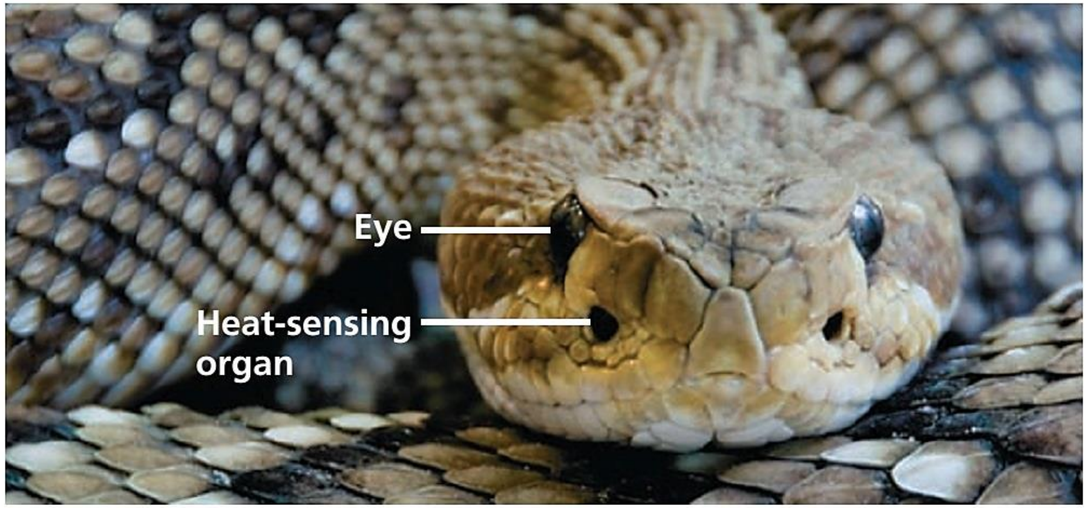
(a) Some migrating animals, such as these beluga whales, apparently sense Earth's magnetic field and use the information, along with other cues, for orientation.

Thermoreceptors

Thermoreceptors detect heat and cold. For example, certain venomous snakes rely on thermoreceptors to detect the infrared radiation emitted by warm prey. These thermoreceptors are located in a pair of pit organs on the snake's head. In humans, thermoreceptors are located in the skin and in the anterior hypothalamus.

Recently, our understanding of thermoreception has increased substantially, thanks to scientists with an appreciation for fiery foods. Jalapeno and cayenne peppers that we describe as "hot" contain a substance called capsaicin. Applying capsaicin to a sensory neuron causes an influx of calcium ions. When scientists identified the receptor protein in neurons that binds capsaicin, they made a fascinating discovery: The receptor opens a calcium channel in response not only to capsaicin but also to high temperatures (42°C or higher). In essence, spicy foods taste "hot" because they activate the same receptors as hot soup and coffee.

Mammals have a variety of thermoreceptors, each specific for a particular temperature range. The capsaicin receptor and at least five other types of thermoreceptors belong to the TRP (transient receptor potential) family of ion channel proteins. Just as the TRP-type receptor specific for high temperature is sensitive to capsaicin, the receptor for low temperatures (below 28°C) can be activated by menthol, a plant product that we perceive to have a "cool" flavor.



(b) This rattlesnake and other pit vipers have a pair of heat-sensing pit organs, one anterior to and just below each eye. These organs are sensitive enough to detect the infrared radiation emitted by a warm prey a meter away. The snake moves its head from side to side until the radiation is detected equally by the two pit organs, indicating that the prey is straight ahead.

Pain Receptors

Extreme pressure or temperature, as well as certain chemicals, can damage animal tissues. To detect stimuli that reflect such noxious (harmful) conditions, animals rely on **nociceptors** (from the Latin nocere, to hurt), also called **pain receptors**. By triggering defensive reactions, such as withdrawal from danger, the perception of pain serves an important function. The capsaicin receptor of mammals can detect dangerously high temperatures, so it also functions as a pain receptor.

Chemicals produced in an animal's body sometimes enhance the perception of pain. For example, damaged tissues produce prostaglandins, which act as local regulators of inflammation. Prostaglandins worsen pain by increasing nociceptor sensitivity to noxious stimuli. Aspirin and ibuprofen reduce pain by inhibiting the synthesis of prostaglandins.