11.1 The Role of the Nervous System

How do organisms make sense of their environment? The flow and processing of information from the environment is astounding, even in relatively simple animals such as bees. The complex nervous system and (to a lesser extent) endocrine system of bees mediate specific behaviours triggered by information from the environment. For example, bees are able to find food and communicate with other bees to share information about the location of food.

Bees do not see colours in the same way that humans do. They see a broader spectrum of light, including ultraviolet light. Bees are primarily attracted to flowers based on the visual characteristics of the flowers. They are particularly attracted to flowers that radiate more ultraviolet light, such as white, bright yellow, blue, or purple flowers (**Figure 1**). Odour is a secondary stimulus, which supplements the visual cues and enables bees to zero in on their floral targets. After collecting nectar and pollen, bees need to navigate back to their hive. They use the Sun as a navigational aid, as well as Earth's magnetic field. They also rely on visual landmarks for orientation.

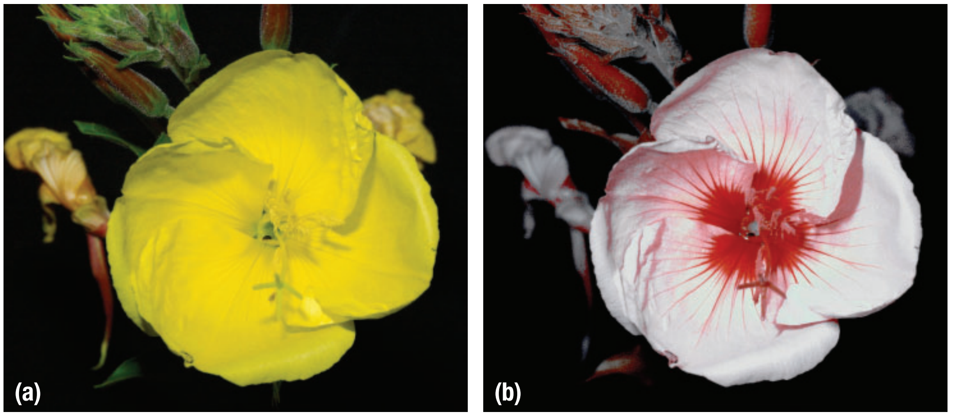

Figure 1 (a) The human eye sees this flower as yellow. (b) A photograph taken with a special filter allows us to see the flower as a bee sees it. Notice the patterns that radiate out from the pollen-producing structure in the centre.

In this section, you will examine the structures of the nervous system and the processes that enable an organism to sense and respond to its external environment and control its internal environment.

Neural Signalling

A **neuron** is a specialized nerve cell that is the functional unit of the nervous system. It allows an organism to receive and respond to both internal and external stimuli. **Neural signalling**—communication by neurons—is the process by which an animal responds appropriately to stimuli. In most animals, the four components of neural signalling are reception, transmission, integration, and response. Reception is the detection of a stimulus. It is performed by neurons and by specialized sensory receptors, such as those in the eyes and skin. Transmission is the movement of a message along a neuron to either another neuron or a muscle or gland. Integration is the sorting and interpretation of multiple neural messages and the determination of the appropriate response. Response is the output or action resulting from the integration of neural messages.

Neural signalling involves three functional classes of neurons (**Figure 2**, next page). **Afferent neurons** (also called sensory neurons) transmit stimuli collected by their sensory receptors to **interneurons**, which integrate the information to formulate an appropriate response. Interneurons are found primarily in the brain and spinal cord. In humans and some other primates, about 99 % of the neurons are interneurons. **Efferent neurons** carry the response signal away from the interneurons to the effectors, which are the muscles and glands. Efferent neurons that carry signals to skeletal muscles

neuron a nerve cell that is capable of conducting nerve impulses

neural signalling the reception, transmission, and integration of nerve impulses by neurons, and the response to these impulses

afferent neuron a neuron that carries impulses from sensory receptors to the central nervous system; also called a sensory neuron

interneuron a local circuit neuron of the central nervous system that relays impulses between afferent (sensory) and efferent (motor) neurons

efferent neuron a neuron that carries impulses from the central nervous system to skeletal muscles; also known as a motor neuron are called motor neurons. The information-processing steps in the nervous system can be summarized as (1) stimulus reception by sensory receptors on afferent neurons; (2) message transmission by afferent neurons to interneurons; (3) integration of neural messages in interneurons; (4) response by the transmission of neural messages by efferent neurons to effectors, where appropriate action occurs.

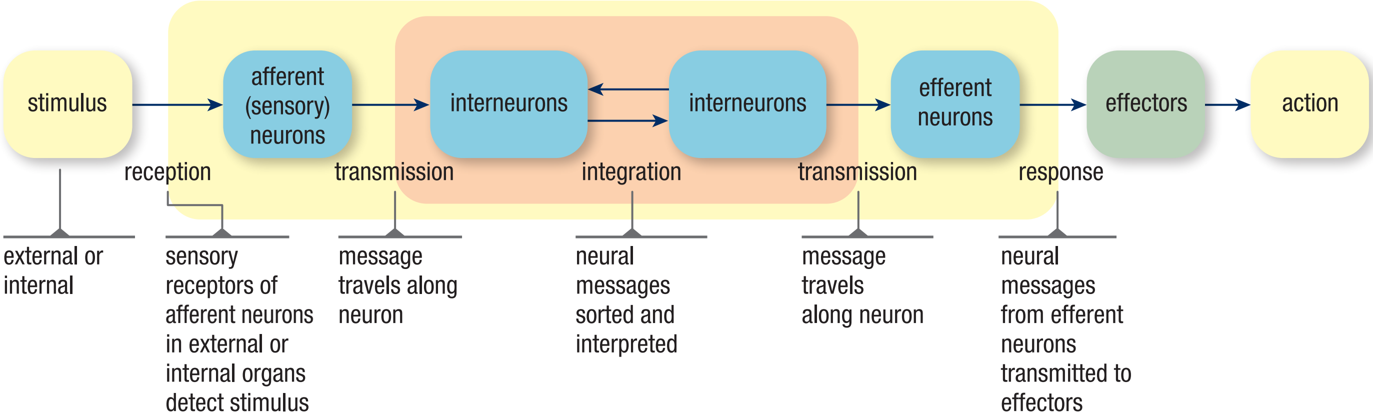

Figure 2 Neural signalling: information-processing steps in the nervous system following an external (e.g., light) or internal (e.g., change in blood pressure or body temperature) stimulus

Neurons vary widely in shape and size. However, all neurons have an enlarged cell body and two types of extensions or processes (**Figure 3**). The cell body, which contains the nucleus and most of the organelles in the cell, synthesizes most of the neuron's proteins, carbohydrates, and lipids. Specialized projections from the cell body conduct electrical signals, which are produced by ions flowing down concentration gradients, through channels in the plasma membrane of the neuron. **Dendrites** (from *dendros* meaning "tree") are generally highly branched projections that form a tree-like outgrowth at one end of the neuron. Dendrites receive the signals and transmit them toward the cell body. **Axons** (from *axon* meaning "axis") are specialized projections that conduct signals away from the cell body to another neuron or an effector. Each neuron usually has a single axon that arises from a junction with the cell body called an axon hillock. The axon has branches at its tip that end as small, button-like swellings called axon terminals. The axon terminals are the points of connection that enable the signals to be transmitted from one neuron to another or from a neuron to an effector. The more terminals in contact with a neuron, the greater its capacity to integrate incoming information.

dendrite a projection of cytosol that carries signals toward the nerve cell body

axon an extension of cytosol that carries nerve signals away from the nerve cell body

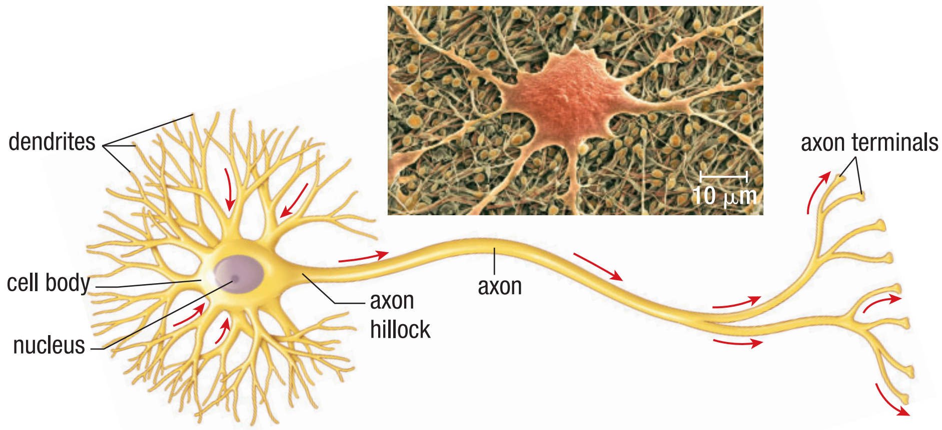

Figure 3 The structure of a neuron (nerve cell). The arrows indicate the direction of the electrical impulse that travels along the neuron. The inset image is a scanning electron micrograph of a motor neuron.

Axons are often very long and extremely thin projections from the cell body. Usually, many axons are bundled together to form nerve fibres of various sizes, commonly referred to simply as "nerves" (**Figure 4**). These nerves branch extensively to relay signals throughout the periphery of the entire body.

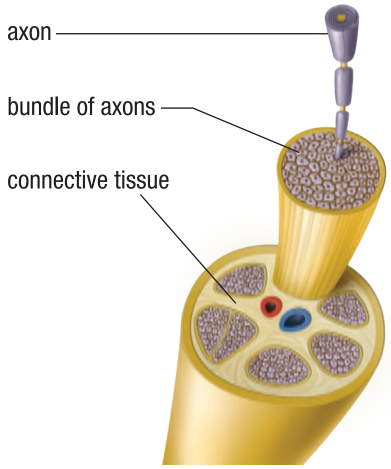

Figure 4 Axons are bundled together to form nerve fibres similar to the way small fibres are bundled together to form a fibre-optic telephone cable.

Connections between the axon terminals of one neuron and the dendrites or cell body of a second neuron form the basic elements of a neuronal circuit. A typical neuronal circuit contains an afferent neuron, one or more interneurons, and an efferent neuron. Interneurons may receive input from several axons and may, in turn, connect to other interneurons and several efferent neurons. In this way, circuits of neurons combine into networks that interconnect the different parts of the nervous system.

Neuron Support System

glial cell a non-conducting cell that is important for the structural support and metabolism of nerve cells

myelin sheath an insulated covering over the axon of a nerve cell

node of Ranvier a regularly occurring gap between sections of myelin sheath along the axon

Not all cells in the nervous system are neurons. **Glial cells** do not conduct electrical signals, but provide nutrition and support to neurons. One type of glial cells, called Schwann cells, form tightly wrapped layers of plasma membrane, called **myelin sheaths**, around axons (**Figure 5**). These myelin sheaths act as electrical insulators due to their high lipid content. The gaps between Schwann cells, called **nodes of Ranvier**, expose the axon membrane directly to extracellular fluids. This arrangement of insulated stretches of axons, punctuated by uninsulated gaps, speeds the rate at which electrical impulses move along the axons.

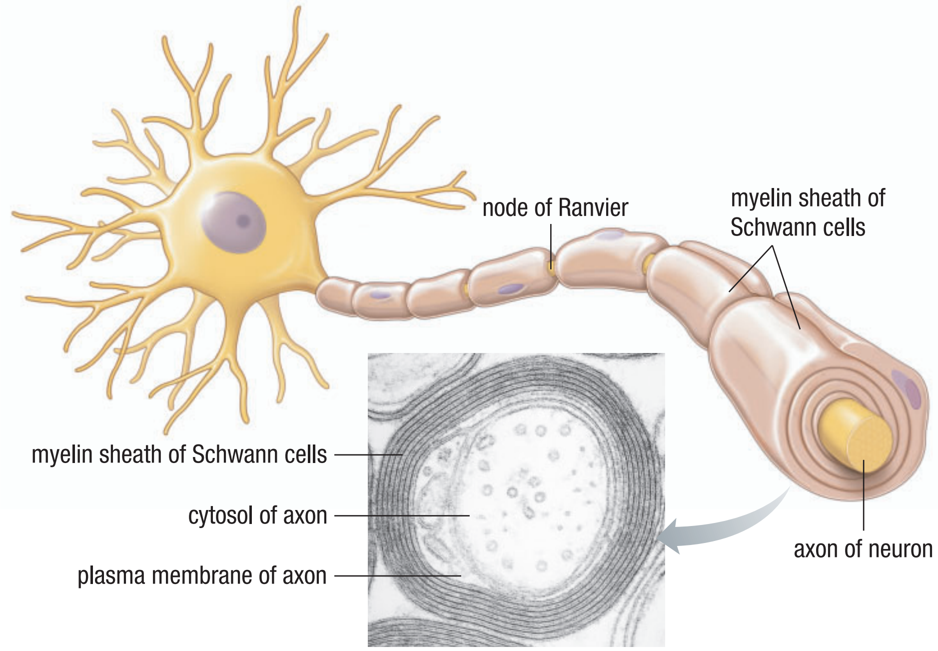

Figure 5 The myelin sheath formed by Schwann cells acts like an electrical insulator. As many as 300 overlapping layers of Schwann cell plasma membrane wind around an axon, like a jelly roll.

Unlike most neurons, glial cells retain the capacity to divide throughout the life of an animal. This capacity allows glial tissues to replace damaged or dead cells. However, it also makes them the source of nearly all brain tumours, which are produced when regulation of glial cell division is lost.

central nervous system (CNS) the body's coordinating centre for mechanical and chemical actions; made up of the brain and spinal cord

peripheral nervous system (PNS) all parts of the nervous system, excluding the brain and spinal cord; relays information between the central nervous system and other parts of the body

The Structure and Organization of the Human Nervous System

The nervous system of most invertebrates and vertebrates, including humans, is made up of two functional subsystems. Interneurons form the **central nervous system (CNS)**, which consists of the brain and spinal cord. The **peripheral nervous system (PNS)** is the subsystem that communicates with the central nervous system. The PNS can be further divided into the **afferent system** (which receives input through receptors and transmits it to the CNS) and the **efferent system** (which carries signals to the muscles and glands that are effectors). "Afferent" refers to carrying *toward*, and "efferent" refers to carrying *away*.

The nervous system is really a system of systems and subsystems that is similar to the collection of neighbourhoods in a large city and the transportation systems that connect these neighbourhoods. A schematic representation of the entire system, including both the CNS and PNS, is illustrated in **Figure 6**. The CNS and PNS will be explored in detail in Sections 11.3 and 11.4.

afferent system the component of the peripheral nervous system that receives input through receptors and transmits the input to the central nervous system

efferent system the component of the peripheral nervous system that carries signals away to the effectors (muscles and glands)

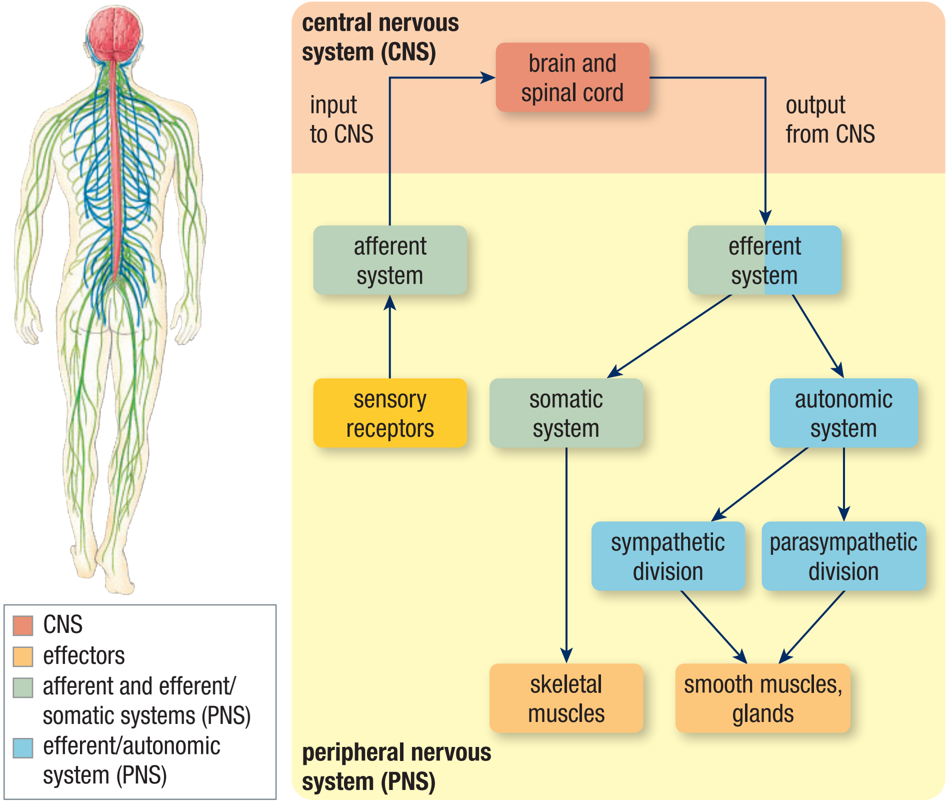

Figure 6 Overview of the human nervous system, comprising the central and peripheral nervous systems (CNS and PNS)

The efferent system is subdivided into the **somatic system** (which communicates with the skeletal muscles) and the **autonomic system** (which communicates with smooth muscles and glands). The somatic system is essentially voluntary, although some contractions of skeletal muscles (reflexes, shivering, and muscle contractions that maintain posture and balance) are unconscious and involuntary. The autonomic system controls mainly involuntary processes, such as digestion, secretion by sweat glands, circulation of the blood, and contraction of smooth muscles in all parts of the body.

The autonomic system is further subdivided into two divisions: the sympathetic division and the parasympathetic division. These divisions are always active and have opposing effects on the organs that they affect, thereby enabling precise control. The **sympathetic division** dominates in situations that involve stress, danger, excitement, or strenuous physical activity. Signals from the sympathetic division increase the force and rate of the heartbeat, raise the blood pressure by vasoconstriction, dilate air passages in the lungs, induce sweating, and dilate the pupils. The **parasympathetic division**, in contrast, dominates during quiet, low-stress situations, such as relaxation. Under its influence, the effects of the sympathetic division, such as rapid heartbeat and elevated blood pressure, are reduced, and maintenance activities, such as digestion, predominate.

somatic system a subdivision of the efferent system (within the PNS); composed of efferent (motor) neurons that carry signals to skeletal muscles in response to external stimuli

autonomic system a subdivision of the efferent system (within the PNS); regulates the internal environment

sympathetic division one of two subdivisions of the autonomic nervous system; increases energy consumption and prepares the body for action

parasympathetic division one of two subdivisions of the autonomic nervous system; stimulates body activities that acquire and conserve energy

Investigation 11.1.1

Testing Learned Responses (p. 554)

You have learned how the nervous system receives information from conditions in the internal and external environment, and responds to those conditions. In this investigation, you will condition an organism to respond differently than usual to external stimuli.

neural circuit the coordination of the receptor, afferent neuron, interneuron, efferent neuron, and effector in response to a stimulus

reflex arc a neural circuit that travels through the spinal cord but does not require the coordination of the brain; allows for reflex actions

Neural Circuits and the Reflex Arc

Ouch! When your finger accidentally comes in contact with something very hot, such as the heating element on a stove, your reaction is instantaneous. You do not need to stop and think about what to do—you immediately pull away your finger. Thermal energy is detected by your skin's pain receptors and thermoreceptors, which stimulate an afferent neuron. The afferent neuron transmits the impulse to at least two interneurons in the spinal cord, which, in turn, relay the impulse to an efferent neuron—a motor neuron that coordinates the rapid withdrawal of your hand from the source of the thermal energy, and perhaps an involuntary scream of pain. Such reactions are involuntary and occur in a fraction of a second, without conscious thought. Processing the same information consciously would require too much time and could result in a serious injury.

This situation is an example of a **neural circuit**, which consists of five components: the receptor, the afferent neuron, the interneuron, the efferent neuron, and the effector. The simplest neural circuit is the **reflex arc**. An example of the reflex arc is the withdrawal reflex that results when your finger touches a very hot object (**Figure 7**). A reflex arc is a circuit that does not require the coordinating effort of the brain.

Interneurons connected to the reflex circuits also send signals to the brain, making you aware of the stimulus that caused the reflex. When a reflex movement withdraws your hand from a hot surface or another damaging stimulus, you feel the pain shortly after the hand is withdrawn. This delay in feeling the pain is the extra time required for the impulses to travel from the neurons of the reflex to the brain.

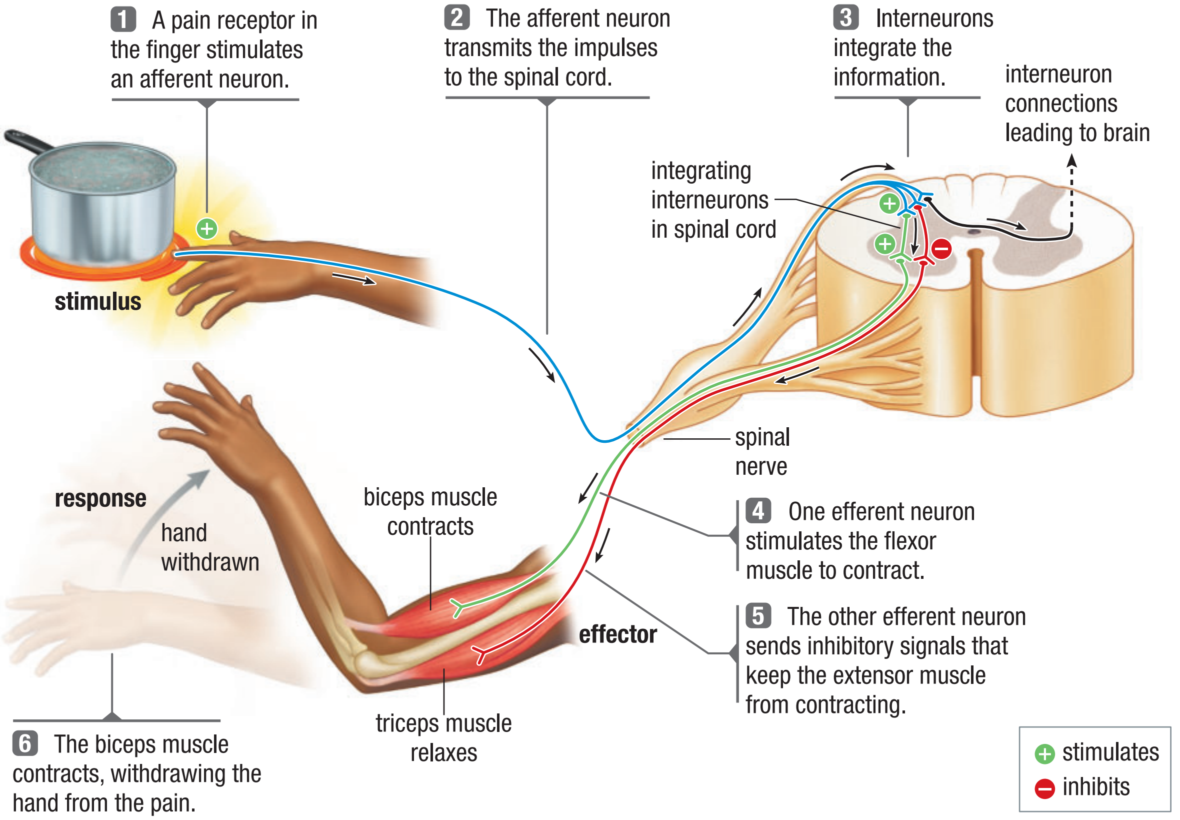

Figure 7 The withdrawal reflex is the result of a series of steps that the nervous system uses to integrate incoming information and respond appropriately. It happens so rapidly that the experience of pain occurs after the hand is already withdrawn from the stimulus, such as the hot stove element.

11.1 Review

Summary

- The nervous system of an animal has four main functions: (1) it receives information about conditions in the internal and external environment, (2) it transmits the message along neurons, (3) it integrates the information to formulate an appropriate response, and (4) it sends out signals to effector tissues or organs.
- Neurons are cells that are specialized for the reception and transmission of electrical signals. They have dendrites (which receive information and conduct signals toward the cell body) and axons (which conduct signals away from the cell body to another neuron or an effector).
- Afferent neurons conduct information from sensory receptors to interneurons, which integrate the information into a response. The response signals are passed to efferent neurons, which activate the effectors that perform the response.
- Glial cells provide structural and functional support to neurons. They help to maintain the balance of ions surrounding the neurons and form insulating layers around the axons.
- The central nervous system (CNS) consists of the brain and spinal cord. It communicates with the peripheral nervous system (PNS), which is made up of the afferent and efferent systems.
- A neural circuit consists of the receptor, the afferent neuron, the interneuron, the efferent neuron, and the effector. The simplest neural circuit is the reflex arc.

Questions

1. (a) Explain the functions of afferent neurons, efferent neurons, interneurons, and effectors.
   (b) Describe how they work together. K/U
2. What is the purpose of the nodes of Ranvier? K/U
3. Which nervous system cells provide a supporting role, rather than transmitting nerve impulses? What is their role? K/U
4. Why do you think reflexes have evolved to occur without the need for the brain to process the information? K/U
5. What is a reflex arc? Describe a simple example of a reflex arc. K/U
6. Neurofibromatosis type 1 is a genetic condition of the nervous system. It is characterized by skin spots with different colorations, and tumours in the nervous system. Use the Internet and other sources to research neurofibromatosis type 1. Prepare a brief report that summarizes the causes, symptoms, and treatments for this condition. Why do you think neurofibromatosis is significantly under-diagnosed? T/I C
7. Has a doctor ever tapped your knee with a rubber hammer? Checking your reflex actions is one of several ways in which a doctor can assess the functioning of your nervous system. Choose three reflexes, and use the Internet and other sources to conduct research on them. Determine the following information about each reflex:
   - a general description of the reflex
   - the person who discovered the reflex and how it was discovered
   - the neurological pathway that the nerve signals follow
   - the significance of the reflex in normal functioning
   - the reason why we test for the reflex

   Prepare a one-page report or create a 5 min audiovisual presentation to share the essential information about the three reflexes you researched. T/I C

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