Chapter 8 – Sensory Neuron Organization and General Senses

Objectives

Given the synopsis in this chapter, competence in each objective will be demonstrated by responding to multiple choice, matching, put-in-order, or fill-in questions, at the level of 85% or greater proficiency for each student.

A. To compare and contrast in a short essay or with diagrams the anatomical organization and function of sensory receptors.
B. To explain the process of sensory transduction and coding.
C. To describe the somatosensory sensations and the receptors responsible for their detection.
D. To explain the circuitry responsible for processing somatosensory signals, including the posterior column-medial lemniscus pathway, the spinothalamic pathway, and the trigeminal sensory pathway.
E. To explain the modulation and filtering of somatosensory signals, especially pain.

Sensory Receptors

Anatomical classes of receptors and sensory neurons

Sensory receptors are either specialized receptors/dendrites of sensory neurons or separate cells that synapse with the dendrites of sensory neurons. The three major anatomical classes of sensory receptors are illustrated in Figure 8.1.

- Free nerve endings are the receptors/dendrites of sensory neurons.
- Encapsulated nerve endings are the receptors/dendrites of sensory neurons enclosed in fibrous connective tissue.
- Accessory sensory receptor cells are separate cells that synapse with the dendrites of sensory neurons and secrete neurotransmitters (usually glutamate) at the synapse.

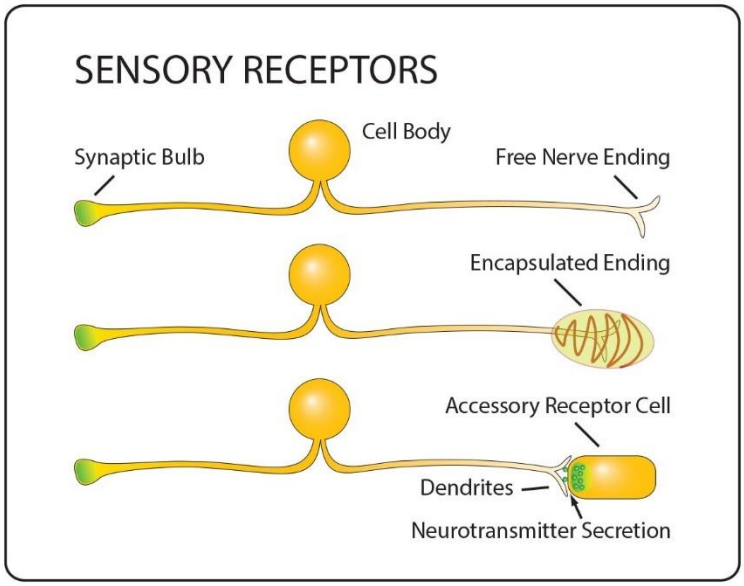


Figure 8.1 © 2019 David G. Ward, Ph.D.

Sensory neurons vary in size and conduction velocity and may be classified as types A-alpha, A-beta, A-delta, and C, as shown in Table 8.1. The larger the axon diameter, the faster the conduction velocity. A hemisection of the spinal cord showing type A-beta, A-delta, and C neurons is illustrated in Figure 8.2.

Table 8.1. Sensory Neurons, Axon Size and Conduction Velocity

Sensory Neuron	Axon Diameter	Conduction Velocity
A-alpha (Aα)	13-20 µm	80-120 m/sec
A-beta (Aβ)	6-12 µm	35-75 m/sec
A-delta (Aδ)	1-5 µm	5-30 m/sec
C	0.2-1.5 µm	0.5-2 m/sec

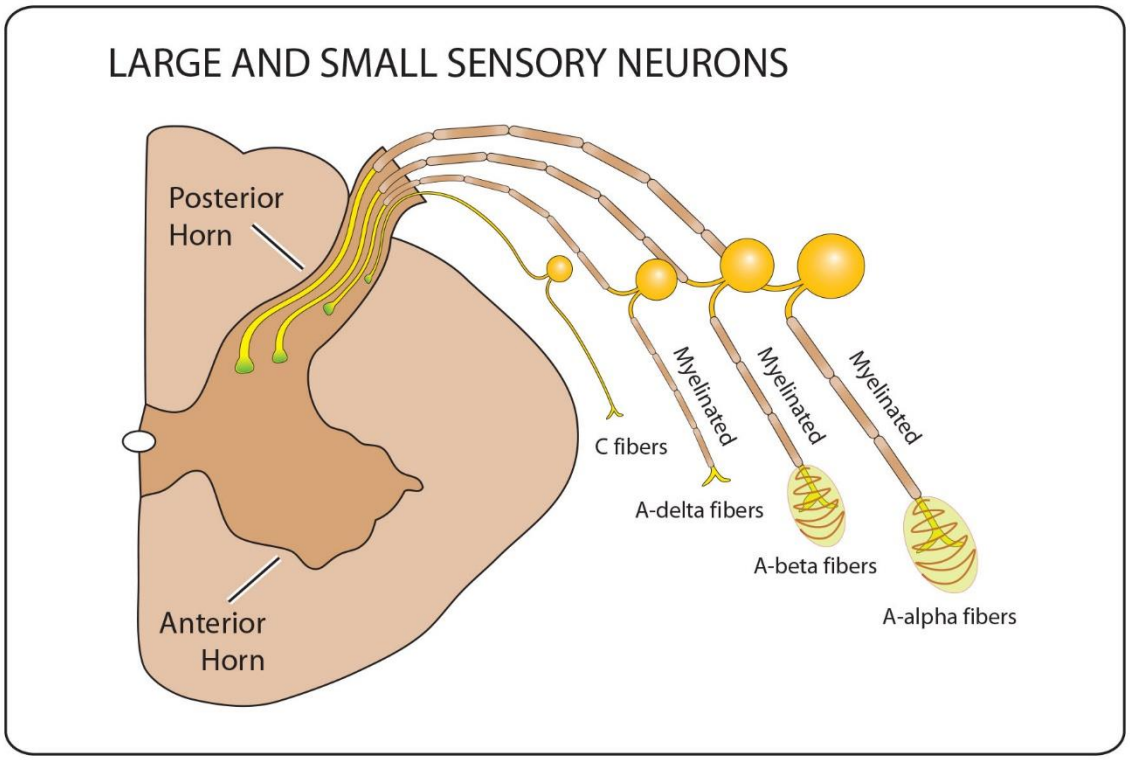


Figure 8.2 © 2014 David G. Ward, Ph.D.

Functional classes of receptors

Sensory receptors fall into five major categories:

- Mechanoreceptors – contain movement gated ion channels, which respond to local movement.
- Thermoreceptors – contain temperature-gated ion channels (TRP [Transient receptor potential] channels), which respond to temperature.
- Chemoreceptors – contain chemical-gated ion channels (TRP channels); or GPCR regulated channels, which respond to local chemistry.
- Nociceptors – contain movement gated channels, and temperature or chemical-gated ion channels (TRP channels); or GPCR regulated channels, which respond to tissue damage.
- Photoreceptors – contain GPCR regulated channels, which respond to light.

Receptors for General senses (Somatosensory, Viscerosensory)

General senses usually refer to sensations related to the skin, muscle, or internal organs. These sensations are typically touch, pressure, temperature, pain, and body chemistry. Sensations related to skin and muscles are called **somatosensory**. Sensations related to the internal organs are called **viscerosensory**.

- **Mechanoreceptors** respond to movement and are responsible for detecting movement.
    - **Cutaneous Mechanoreceptors** respond to touch, pressure, and vibration.
        - Usually are encapsulated nerve endings; sometimes are free nerve endings.
        - Touch, pressure, and vibration is detected by movement gated ion channels in the receptor.
        - Myelinated type A-beta neurons (axons) conduct the sensation of touch, pressure and vibration.
    - **Proprioceptors** respond to stretch of muscles and tendons and are responsible for detecting the position of joints and muscles.
        - Proprioceptors usually are encapsulated nerve endings of sensory neurons.
        - Stretch is detected by movement gated ion channels in the receptor.
        - Myelinated type A-alpha neurons (axons) conduct the sensation of muscle stretch.
    - **Baroreceptors** respond to stretch of blood vessels and cardiac chambers and are responsible for detecting the pressure in blood vessels and heart.
        - Baroreceptors may be free or encapsulated nerve endings of sensory neurons.
        - Stretch is detected by movement gated ion channels in the receptor.
- **Thermoreceptors** respond to changes in temperature and are responsible for detecting such things as hot and cold.
    - Thermoreceptors usually are free nerve endings of sensory neurons.
    - Temperature is detected by temperature-gated ion channels (TRP channels) in the receptor.
- **Chemoreceptors** respond to chemical changes and are responsible for detecting such things as hydrogen ions.
    - Chemoreceptors usually are free nerve endings of sensory neurons.
    - Chemicals are detected by chemical-gated ion channels (TRP channels); or GPCR regulated channels in the receptor.
- **Nociceptors** respond to tissue damage and inflammation.
    - Nociceptors usually are free nerve endings of sensory neurons.
    - Tissue damage is detected by movement gated channels, or temperature gated ion channels (TRP channels), or GPCR regulated channels in the receptor.
    - Inflammation is detected by chemical-gated ion channels (TRP channels), or GPCR regulated channels, in response to chemical messengers, such as inflammatory peptides and eicosanoids.
    - Unmyelinated type C neurons (axons) conduct slow or aching pain.
    - Myelinated type A-delta neurons (axons) conduct fast or prickling pain.

Receptors for Special senses (Smell, Taste, Hearing, Balance, Vision)

Special senses usually refer to sensations related to the ears, tongue, nose, and eyes: hearing (**Auditory**), balance (**Vestibular**), taste (**Gustatory**), smell (**Olfactory**), and sight (**Visual**).

- **Auditory Mechanoreceptors** (Hair cells) respond to movement in the cochlea and are responsible for the detection of sound
    - Auditory Mechanoreceptors are accessory sensory receptor cells.
    - Movement is detected by movement gated ion channels in the hair cells.
- **Vestibular Mechanoreceptors** (Hair cells) respond to movement in the vestibule and are responsible for the detection of balance.
    - Vestibular Mechanoreceptors are accessory sensory receptor cells.
    - Movement is detected by movement gated ion channels in the hair cells.
- **Gustatory Chemoreceptors** (Taste Cells) respond to chemical changes and are responsible for the detection of tastes.
    - Gustatory chemoreceptors are accessory sensory receptor cells.
    - Taste is detected by chemical-gated ion channels; or GPCR regulated channels in the taste cells.
- **Olfactory chemoreceptors** (Olfactory Cells) respond to chemical changes and are responsible for the detection of odors.
    - Olfactory chemoreceptors are accessory sensory receptor cells.
    - Smell is detected by GPCR regulated channels in the olfactory cells.
- **Visual Photoreceptors** (Rods and Cones) respond to light and are responsible for the detection of visual images.
    - Photoreceptors are accessory sensory receptor cells.
    - Light is detected by GPCR regulated channels in the rods and cones.

Sensory Transduction and Coding

Sensory transduction

A sensory stimulus, such as touch acting on movement gated channels of a tactile receptor, causes a small change in the membrane potential that is proportional to the stimulus. Please refer to Chapter 7, Figure 7.5. If the graded potential reaches about -60 mV to -55 mV in the axon, the threshold depolarization is reached to generate an action potential. The action potential is then propagated to the central nervous system.

Sensory coding

Sensory coding includes the processing of sensory information by the receptors and by the brain. Receptors for specific sensory modalities process and send information to specific regions of the brain where patterns of sensory activation are processed in networks.

The pattern of the action potentials from single and multiple neurons provides information about strength, duration, and other characteristics of the sensory stimuli. Some sensory receptors are rapidly adapting and others are slowly adapting. As shown in Figure 8.3, depending on the characteristics of the receptor, the same sensory stimulus (for example, cutaneous indentation) causes very different patterns of action potential generation.

- Rapidly adapting receptors produce transient responses to the stimulus.
- Slowly adapting receptors produce responses that are more proportional to the stimulus.

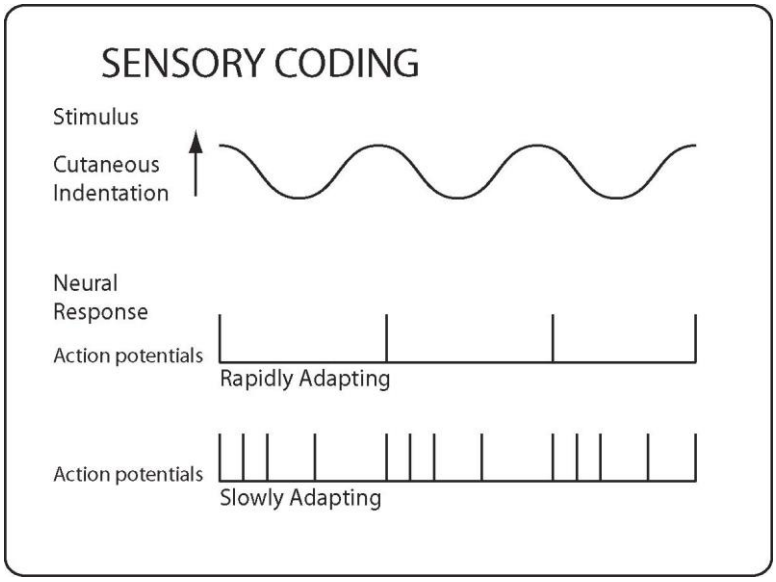


Figure 8.3 © 2007 David G. Ward, Ph.D.

Adaptation and central processing

Sensory stimulation frequently goes unnoticed. The reason for this is due to reductions in responsiveness of the sensory receptors and /or to the neurons in the central nervous system. First, as noted above, sensory stimulation of rapidly adapting receptors will cause only a transient response in the sensory neuron. Second, continued activity in a sensory neuron often causes only a transient response of the target neuron in the central nervous system.

- Reduced sensitivity of the receptor is called Sensory Adaptation.
- A reduced response of neurons in the central nervous system is called Central Adaptation (Habituation).

Central adaptation plays a critical role in our ability to filter and ignore irrelevant sensory information. (See Modulation and Filtering of Sensory Information in this chapter.)

Somatosensory Sensation

Touch, vibration, pressure

Stimulation of cutaneous mechanoreceptors produces the sensation of touch, vibration, and pressure. Photomicrographs of two types of encapsulated mechanoreceptors, a tactile (Meissner's) corpuscle and a lamellated (Pacinian) corpuscle, are shown in Figure 8.4.

- Tactile (Meissner's) corpuscles are encapsulated receptors that detect fine touch and vibration, and are rapidly adapting.
- Lamellated (Pacinian) corpuscles are encapsulated receptors that detect pressure, and are rapidly adapting.
- Signals about touch, vibration, and pressure are mediated by A-beta neurons.

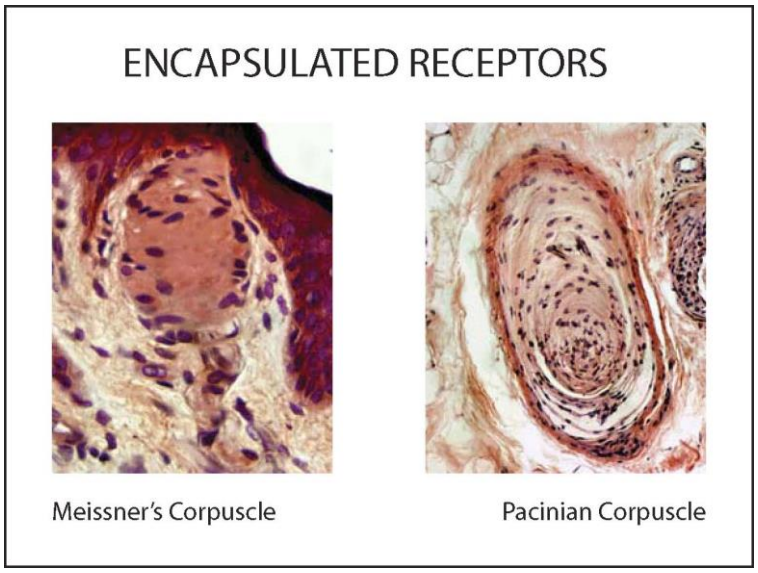


Figure 8.4 © 2007 David G. Ward, Ph.D.

Stretch of Muscle and Tendons

Stimulation of proprioceptors provides information about muscle stretch and body position and induces reflexive adjustment of muscle length.

- Muscle spindles contain spiraled free nerve endings that detect stretch of the intrafusal muscle and thus of skeletal muscles, and are slowly adapting.
    - Signals about muscle stretch are mediated by A-alpha neurons.
- Golgi tendon organs are free nerve endings that detect stretch of tendons, and are slowly adapting.
    - Signals about tendon stretch are mediated by A-beta neurons.

Pain

Stimulation of cutaneous nociceptors produce the sensation of pain, autonomic responses, fear and anxiety, and induces reflexive withdrawal.

- Fast or prickling pain that is easily localized is mediated by myelinated type-A-delta neurons.
- Slow or aching pain that is poorly localized is mediated by unmyelinated type-C neurons.

Stimulation of nociceptors in the viscera also produces the sensation of pain. However, the pain often seems to be localized to a body surface and is called referred pain. This is because many neurons in the central nervous system often receive input from both somatic and visceral sensory neurons.

Processing of Somatosensory Signals

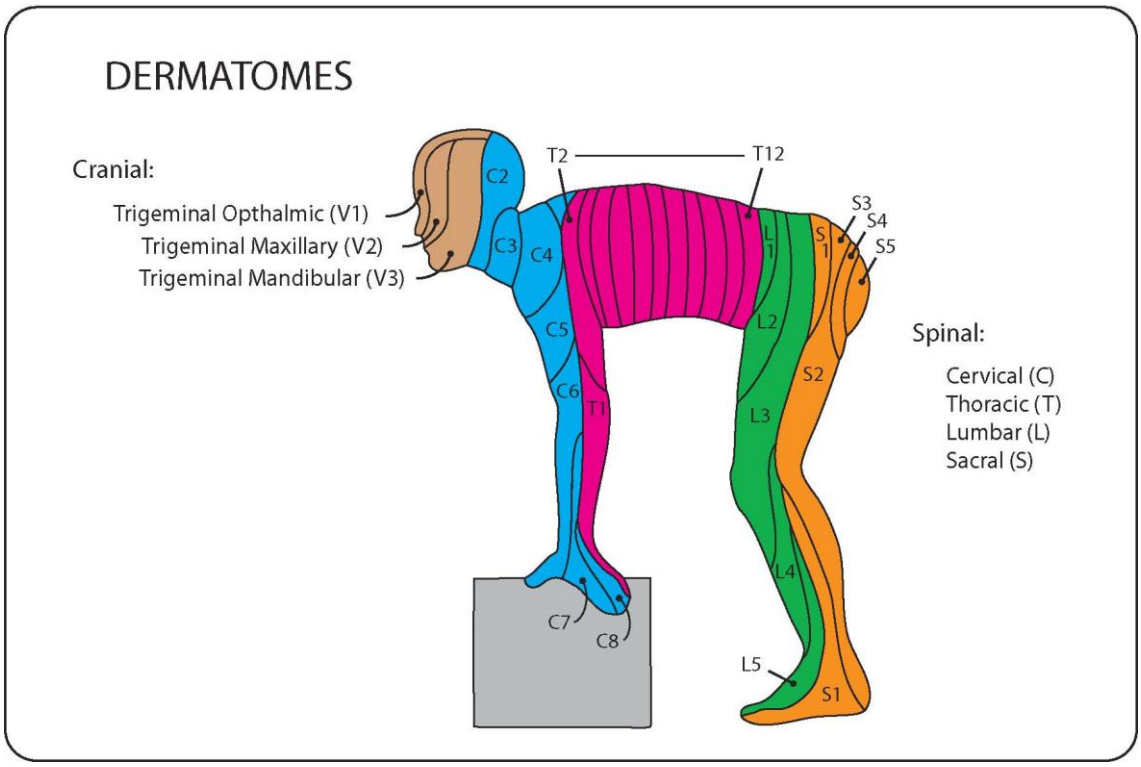
The sensation of light touch, touch, pressure, vibration, temperature and pain are determined through a series of neural connections (pathways) that extend from the sensory neurons (**first order neurons**), to spinal or brainstem neurons (**second order neurons**) to the contralateral thalamus (**third order neurons**), and to the contralateral primary somatosensory cortex (**fourth order neurons**). Accordingly, somatosensory stimulation of one side of the body reaches the opposite side of the thalamus and cerebral cortex.

Sensory receptors located below the head and in the back of the head connect first to spinal pathways (posterior column pathways and spinothalamic pathways). Sensory receptors located in the front and side of the head connect first to brainstem pathways (trigeminal sensory pathways).

Dermatomes

The strip of skin that is innervated by the cutaneous branches of a given cranial or spinal nerve is called a dermatome. The dermatomes associated with the trigeminal nerve are represented with V1-V3. The dermatomes associated with the spinal cervical nerves are represented by C1-C7; with the thoracic nerves by T1-T12; with the lumbar nerves by L1-L5; and with the sacral nerves by S1-S5. The dermatomes of the body are illustrated in Figure 8.5. It is useful clinically to examine dermatomes that have distinct relationships to landmarks on the body. A few examples are noted below.

- V1 is represented by the nose.
- C7 is represented by the index finger.
- The border between T4 and T5 corresponds to the nipples.
- T10 is represented by the navel.
- L1 is represented by the pelvic rim.
- L5 is represented by the big toe.
- S4 is represented by the genitalia.



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Cortical somatotopic organization

Not only do specific spinal and cranial nerves innervate specific regions of the body surface, the central neural connections of these nerves also represent the specific regions of the body surface. As shown in Figure 8.6, the primary somatosensory cortex contains a somatotopic representation of the body surface which is laid out in a "foot-to-tongue" pattern. The greater the density of receptors in the body surface, the larger the representation in the somatosensory cortex. The hands, mouth and lips have a high density of receptors and a very large cortical representation. In contrast, the back has a low density of receptors and a very small cortical representation.

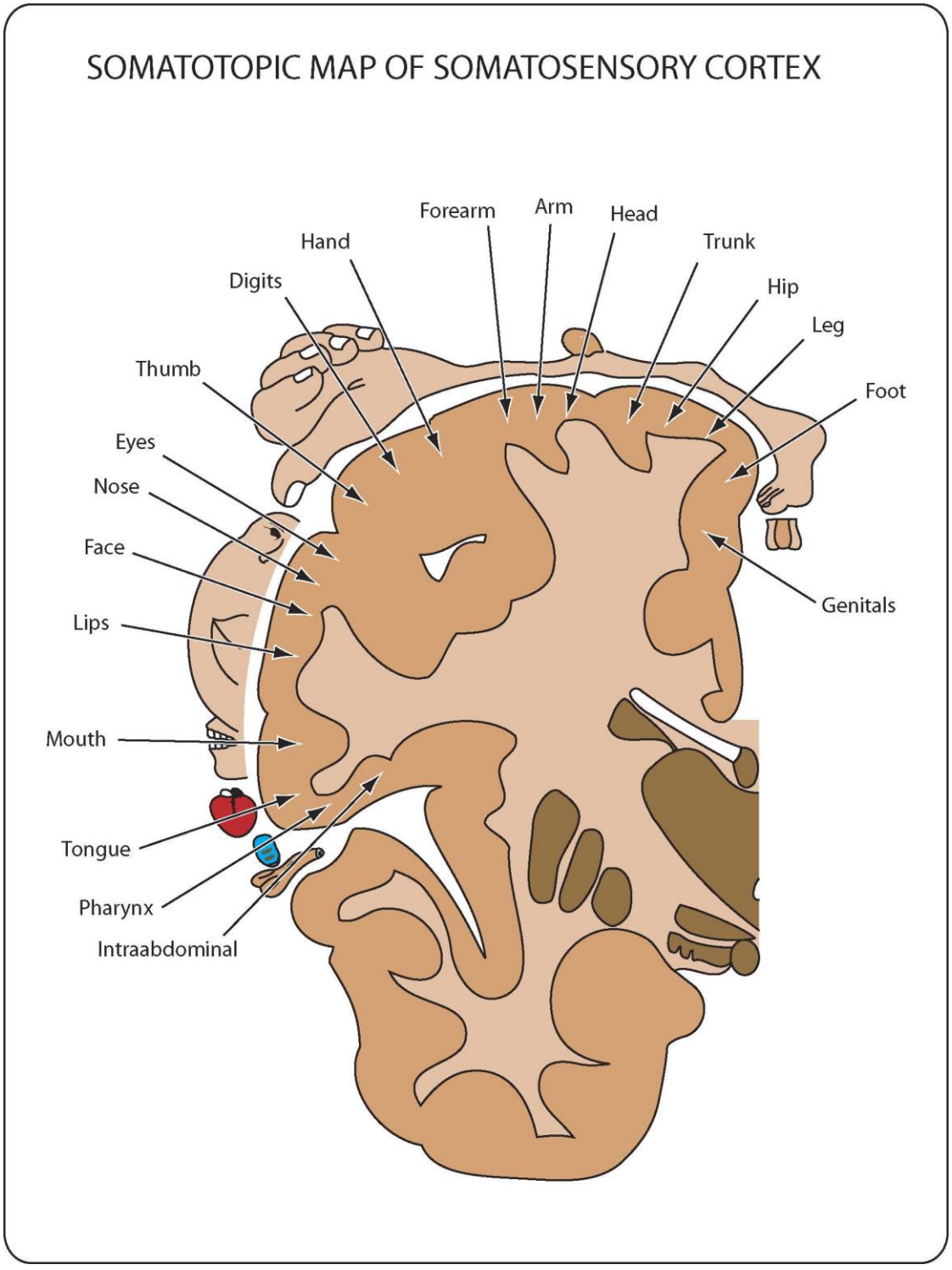

Figure 8.6 © 2007 David G. Ward, Ph.D.

Posterior column – medial lemniscus pathway

The posterior column - medial lemniscus pathway originates from sensory neurons detecting fine (delicate) touch, vibration, muscle stretch and tension, and visceral pain. The posterior column - medial lemniscus pathway is illustrated in Figure 8.7.

- Axons from sensory neurons (first order neurons) travel through the **posterior horns** and into the **posterior columns** on the same side of the body (ipsilateral).
- The axons of the first order neurons in the posterior columns synapse on second order neurons in the **posterior column nuclei** on the same side of the body (ipsilateral).
- The axons of second order neurons in the posterior column nuclei crossover to travel in the **medial lemniscus** on the opposite side of the brain (contralateral) to synapse on third order neurons in the contralateral **thalamus** (ventral posterior nucleus).
- The axons of the third order neurons in the thalamus travel in the **internal capsule** to synapse on fourth order neurons in the **primary somatosensory cortex**.
- A somatotopic organization is maintained throughout these pathways.

Spinothalamic Pathways

The lateral spinothalamic pathways originate from sensory neurons detecting pain and temperature; the anterior spinothalamic pathways originate from sensory neurons detecting pressure and crude touch. The lateral spinothalamic pathway is illustrated in Figure 8.8.

- Axons from sensory neurons (first order neurons) travel to synapse on second order neurons in the **posterior horn** on the same side of the body (ipsilateral).
- The axons of the second order neurons in the posterior horn crossover to travel in **spinothalamic tract** on the opposite side of the brain (contralateral) to synapse on third order neurons in the contralateral **thalamus** (ventral posterior nucleus).
- The axons of the third order neurons in the thalamus travel in the **internal capsule** to synapse on fourth order neurons in the **primary somatosensory cortex**.
- A somatotopic organization is maintained throughout these pathways.

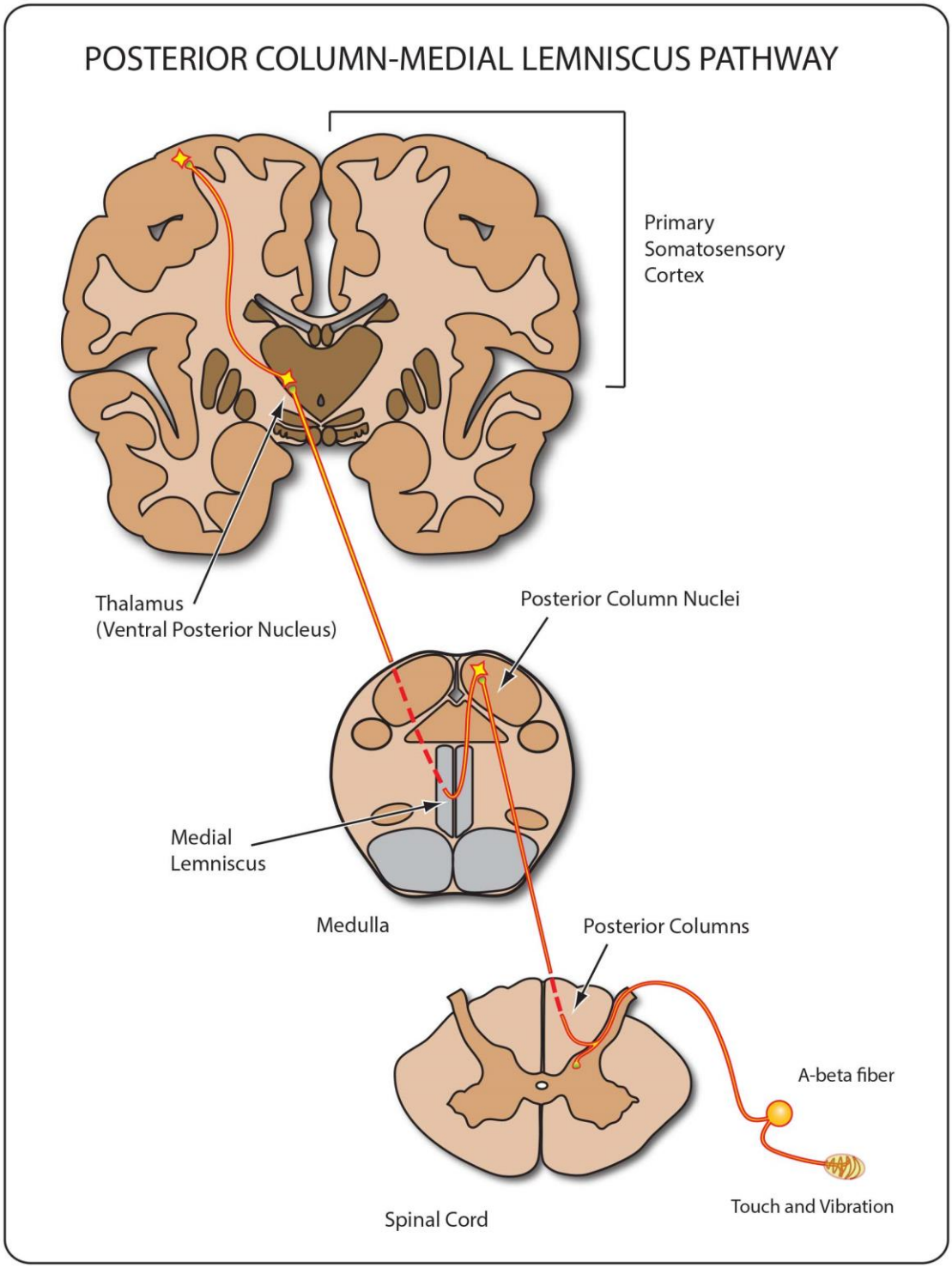

Figure 8.7 © 2020 David G. Ward, Ph.D.

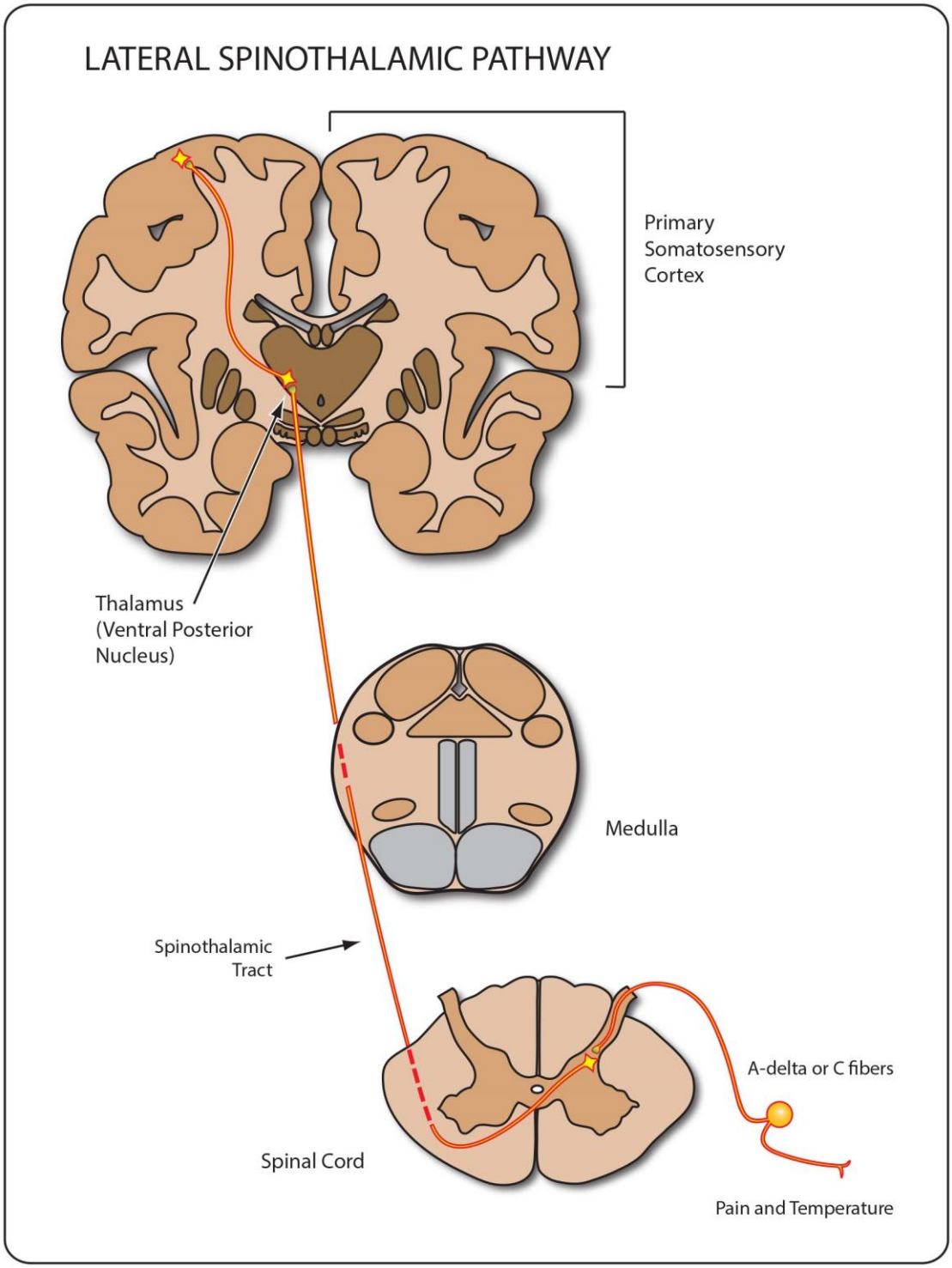

Figure 8.8 © 2020 David G. Ward, Ph.D.

Trigeminal Sensory Pathways

The trigeminal sensory pathways originate from sensory neurons detecting fine touch, vibration, muscle stretch and tension, pain, temperature, and crude touch of the **face**. The trigeminal sensory pathway is illustrated in Figure 8.9.

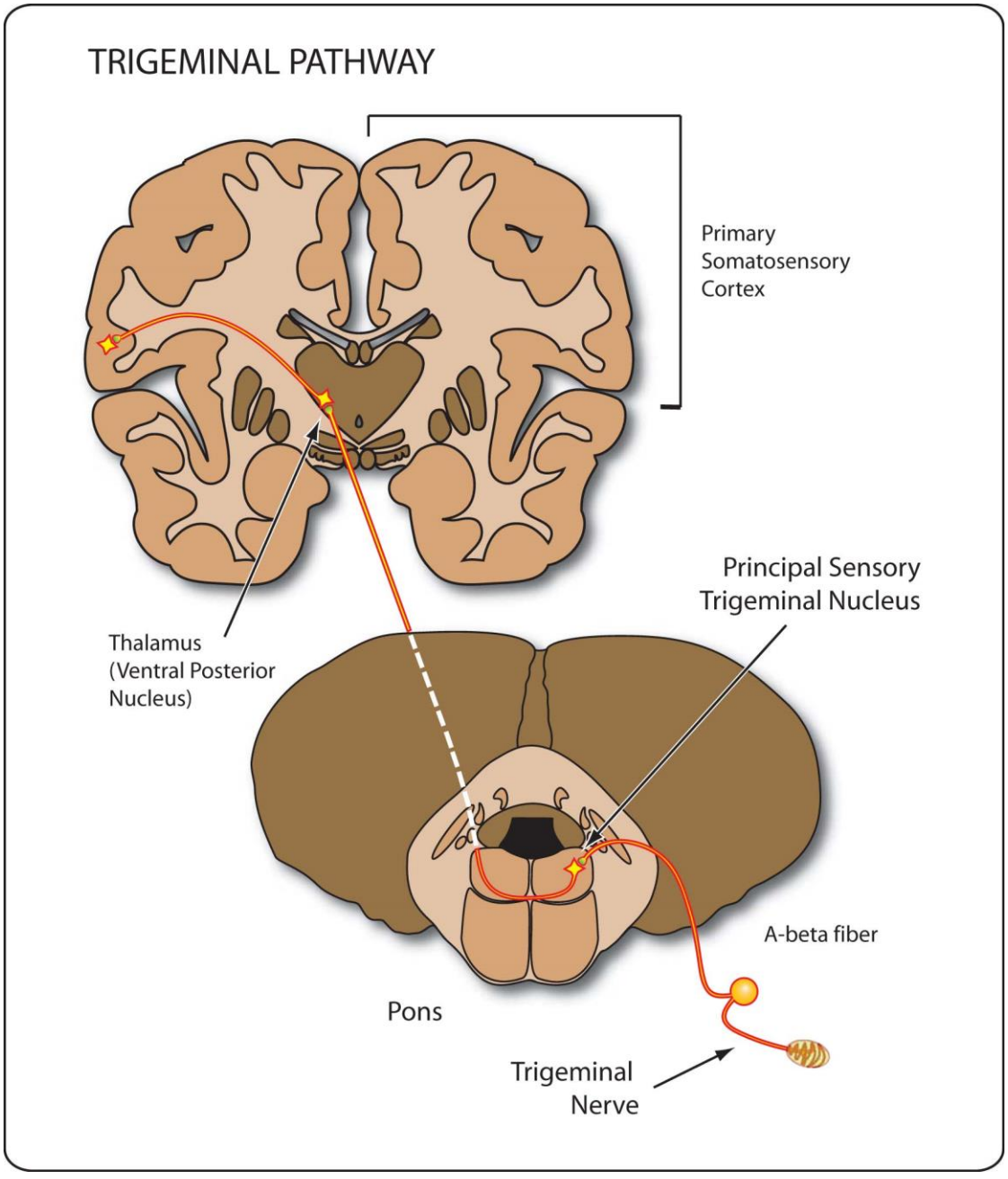

Figure 8.9 © 2010 David G. Ward, Ph.D.

- Axons from sensory neurons (first order neurons) travel from the **semilunar ganglia** into the **pons**, on the same side of the body (ipsilateral).

- The first order neurons conveying signals about touch, pressure, and vibration synapse on second order neurons in the **principal sensory trigeminal nucleus** on the same side of the body (ipsilateral).
- The axons of the second order neurons crossover to travel in the **trigeminal lemniscus** on the opposite side of the body (contralateral).to synapse on third order neurons in the contralateral **thalamus** (ventral posterior nucleus).
- The axons of the third order neurons in the thalamus travel in the **internal capsule** to synapse on fourth order neurons in the **primary somatosensory cortex**.
- A somatotopic organization is maintained throughout these pathways.

Modulation and Filtering of Sensory Information

Modulation of pain

Inhibitory interneurons are able to inhibit second order neurons that transmit pain signals from unmyelinated type-C or myelinated type- A-delta neurons.

- Inhibitory interneurons are often stimulated by type-A-beta neurons that conduct signals about touch, pressure and vibration. Thus stimulation of cutaneous receptors can suppress pain.
- Descending pathways from the brain stem (**periaqueductal gray**, **nucleus raphe magnus**) are also able to suppress pain. The inhibitory effects appear to involve parallel opioid, endocannabinoid, and serotonin neurotransmitter systems. The site(s) of action may be on axon terminal of first order neurons or on the dendrites of second order neurons. Stimulation of Mu-opioid receptors on presynaptic terminals by opioids, markedly inhibits transmission of signals from nociceptor neurons. Stimulation of CB1 receptors and other GPCRs on presynaptic terminals by endocannabinoids, markedly inhibits transmission of signals from nociceptor neurons Activation of 5-HT-1A receptors on presynaptic terminals by serotonin, inhibits glutamate release from the sensory neurons and reduces pain transmission.

The general organization of descending pathways from the periaqueductal gray and nucleus raphe magnus involved in the modulation of pain and analgesia is illustrated in Figure 8.10.

Filtering of sensory signals

Modulation of pain is an example of the central nervous system playing a role in filtering or selecting the sensory information upon which we act and are consciously aware. In addition, the central nervous system, acting through descending pathways, filters most sensory information in the spinal cord, brainstem and thalamus. The thalamus is seen anatomically and functionally as the “gateway” to the cerebral cortex. Because of these

filtering mechanisms little of the original sensory information at any given time reaches the cerebral cortex. This filtering process is sometimes called selective attention.

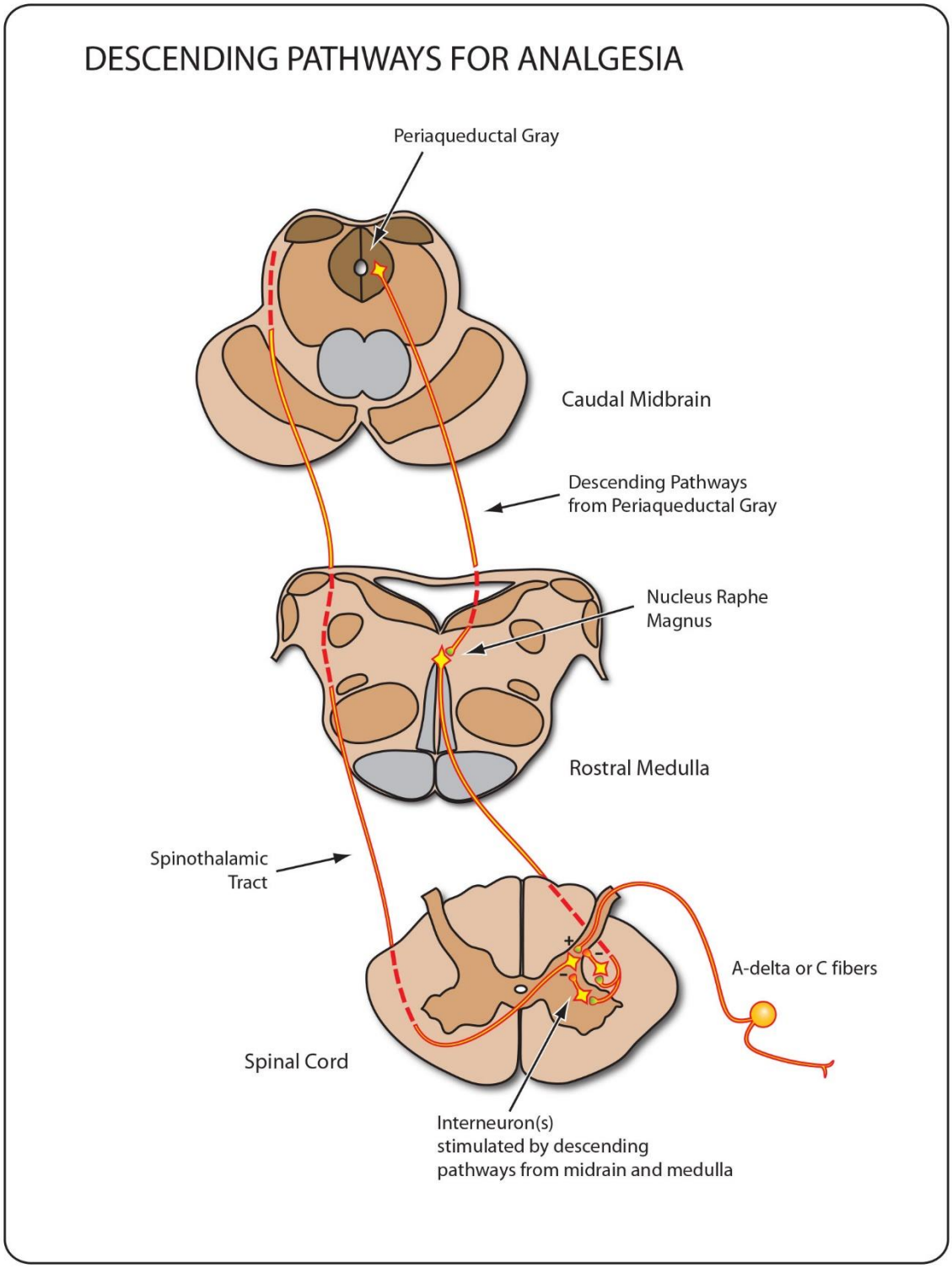

Figure 8.10 © 2014 David G. Ward, Ph.D.

Quiz Yourself

1-5. Matching (in the context of sensory neurons)

A)	sensory receptors/dendrites	generate nervous signals	1) _____
B)	peripheral axon	release neurotransmitters	2) _____
C)	synaptic bulbs	detect chemical or physical signals	3) _____
D)	central axon	conduct signals toward the synaptic bulb	4) _____
		conduct signals from the receptors/dendrite	5) _____

6-10. Matching

A)	C fibers	are the axons of most mechanoreceptor neurons	6) _____
B)	A-delta fibers	conduct signals about touch, pressure, vibration	7) _____
C)	A-beta fibers	are the axons of nociceptor neurons	8) _____
D)	A and B	conduct fast or prickling pain	9) _____
E)	All of the above	conduct slow or aching pain	10) _____

11-15. Matching

A)	Nociceptors	respond to local movement	11) _____
B)	Photoreceptors	respond to local chemicals	12) _____
C)	Chemoreceptors	respond to tissue damage	13) _____
D)	Thermoreceptors	respond to temperature	14) _____
E)	Mechanoreceptors	respond to light	15) _____

16-20. Place in order the events for detecting and transferring the effects of sensory stimulation.

A)	The stimulus alter the permeability of the sensory receptor membrane	16) _____
B)	Neurotransmitter is released onto specific neurons in the CNS	17) _____
C)	The receptor (dendritic) potential reaches threshold	18) _____
D)	The action potential is propagated to the CNS	19) _____
E)	An action potential is generated	20) _____

Fill in

21. Sensory receptors are commonly part of the sensory neuron's _____.

22. Sensory transduction converts a _____ signal into a neural signal.

23. In the dorsal column pathways the sensory neurons synapse in the _____.

24. In the spinothalamic pathways the sensory neurons synapse in the _____ _____.

25. Modulation of pain depends on the _____ of nervous transmission.

Study Questions

1. Describe the organization of sensory neurons and accessory sensory cells.
2. Describe the general mechanisms responsible for the transduction of sensory information.
3. Explain with diagrams the circuitry responsible for processing somatosensory signals, in the posterior column and spinothalamic pathways.
4. Explain how synaptic connections are involved in the filtering of sensory information.
5. Explain the basis for referred pain and the modulation of pain.