The Somatic Sensory System

Introduction

The somatic sensory system is sensitive to many kinds of stimuli throughout the body:

- Receptors are distributed throughout the body, rather than being concentrated at small specialized locations.
- The somatic sensory system is a group of at least four senses, rather than a single one:
    - Touch
    - Temperature
    - Pain
    - Body position

Touch

Mechanoreceptors of the Skin

Mechanoreceptors in the skin consist of sensory nerve endings with movement sensitive ion channels:

- Found deep in the dermis, have large receptive fields, and respond to pressure.
    - Pacinian Corpuscles (Lamellated Corpuscles) are large and are rapidly adapting.
    - Ruffini's endings are smaller, respond to pressure and are slowly adapting.
- Found in the dermal papilla, have small receptive fields, and respond to touch and pressure.
    - Meissner's Corpuscles (Tactile Corpuscles) are much smaller and are rapidly adapting.
    - Merkel's disks are nerve endings next to the epidermis and are slowly adapting.

Two-Point Discrimination

The density of the mechanoreceptors in the skin determines the receptive field size.

- High density of receptors is associated with small receptive fields.
- Low density of receptors is associated with large receptive fields.

Primary Sensory Neurons and Afferent Axons

The somatic sensory receptors are the nerve endings of primary sensory neurons. Anatomically these neurons are unipolar. The axons that carry information from the somatic sensory receptors fall into four categories.

- Aα – large myelinated axons from proprioceptors.
- Aβ – medium myelinated axons from mechanoreceptors.
- Aδ – small myelinated axons from pain and temperature receptors.
- C – Small myelinated axons from temperature, pain, and itch receptors.

The Spinal Cord

Most of the somatic sensory information enter the central nervous system by way of the spinal cord and spinal nerves.

Segmental Organization of the Spinal Cord

- There are 30 pairs of dorsal (posterior) and ventral (anterior) roots that form 30 pairs of spinal nerves.
- These 30 pairs of nerves pass through 30 notches that are located between the vertebrae.
- Accordingly, the spinal cord is divided into 30 segments, each associated with a pair of nerves.

Sensory Organization of the Spinal Cord

- Specific areas of the body are innervated by each pair of spinal nerves.
- Axons of primary somatic sensory neurons from specific areas of the body enter into specific segment of the spinal cord.
- These primary sensory neurons synapse upon secondary sensory neurons in the central nervous system.
    - Some primary sensory neurons synapse onto secondary sensory neurons in the spinal cord, especially in the dorsal (posterior) horns.
    - Other primary sensory neurons pass through the spinal cord to synapse onto secondary sensory neurons in the brain stem.

The Dorsal Column-Medial Lemniscal Pathway

Information from touch receptors below the face passes predominantly through the dorsal column-medial lemniscal pathway.

- Axons of primary somatic sensory neurons travel through spinal nerves, through dorsal (posterior) roots, through the dorsal (posterior) horn, and into the dorsal (posterior) columns of the spinal cord.
- These primary axons terminate (synapse) onto secondary neurons in the dorsal (posterior) column nuclei of the medulla oblongata.
- Axons from the secondary neurons crossover and travel through the medial lemniscus.
- These secondary axons synapse onto tertiary neurons in the ventral posterior nucleus of the thalamus.
- Axons from the tertiary neurons synapse onto neurons in the primary somatosensory cortex.
- Information is altered every time it passes through a set of synapses.
    - Responses are enhanced by collateral inhibition.
    - Signal strength is increased or decreased.
    - Information is filtered.
    - Both the thalamus and the dorsal column nuclei are controlled by the cerebral cortex.

The Trigeminal Touch Pathway

Information from touch receptors of the face passes predominantly through the trigeminal touch pathway.

- Axons of primary somatic sensory neurons travel through cranial nerves and into the brain stem.
- These primary axons terminate (synapse) onto secondary neurons in the principal sensory trigeminal nuclei.
- Axons from the secondary neurons crossover and travel toward the thalamus.
- These secondary axons synapse onto tertiary neurons in the ventral posterior nucleus of the thalamus.
- Axons from the tertiary neurons synapse onto neurons in the primary somatosensory cortex.

Somatosensory Cortex

The somatosensory cortex is located in the postcentral gyrus, just posterior to the central sulcus.

- The primary somatosensory cortex (S1) (area 3b) receives axons from the ventral posterior nucleus of the thalamus.
- Area 3a receives information from proprioceptors (measure muscle length)
- Area 1 receives axons from neurons in area 3b that carry information about texture.
- Area 2 receives axons from neurons in area 3b that carry information about size and shape.
- The thalamic input to the primary somatosensory cortex terminates (synapses) mainly in layer IV
    - The neurons in layer IV connect to other layers.
    - Neurons with similar inputs and responses are stacked vertically in columns.

Cortical Somatotopy

- Areas of the body are mapped onto the somatosensory cortex.
- The relative size of the cortex devoted to each body part is correlated with the density of the receptor input from that part.

Cortical Map Plasticity

- Cortical maps are dynamic and adjust depending the amount of sensory experience.

Posterior Parietal Cortex

The posterior parietal cortex appears to be involved in:

- Perception and interpretation of spatial relationships.
- Accurate body image.
- Learning tasks involving coordination of the body in space.

Pain

Nociceptors and the Transduction of Painful Stimuli

Nociceptors respond to damage or to stimuli that could cause damage.

- The simple deformation of the nociceptor membrane causes the cell to depolarize and generate an action potential.
- Damaged cells can release a number of substances that cause ion channels on nociceptor channels to open. These include:
    - Proteases that break down kininogen to form bradykinin that binds to receptors that open ion channels.
    - ATP that binds directly to ATP gated ion channels.
    - K^+ ions that directly depolarize neuronal membranes.
    - Heat sensitive ion channels.
    - H^+ ion gated ion channels.

Types of Nociceptors

- Mechanical nociceptors.
- Chemical nociceptors.
- Thermal nociceptors.

Hyperalgesia

- Pain sensitivity is increased in response to bradykinin, prostaglandins, substance P, and histamine.

Primary Afferents and Spinal Mechanisms

- Primary sensory neurons with Aδ axons carry information about fast, sharp, first pain.
- Primary sensory neurons with C axons carry information about duller, longer lasting, second pain.
- Primary nociceptor axons synapse in the substantia gelatinosa (outer part of dorsal horn) where glutamate is released and substance P may be co-secreted.
- There is considerable mixing of signals from cutaneous and visceral nociceptors.

Ascending Pain Pathways

The Spinothalamic Pain Pathway

- Axons of second order neurons in the substantia gelatinosa crossover and travel through the spinothalamic tract in the spinal cord and then alongside the medial lemniscus in the brain stem.

The Trigeminal Pain Pathway

- Axons of primary nociceptor neurons synapse onto second order neurons in the spinal trigeminal nucleus of the brain stem.

- Axons of second order neurons crossover and travel through the trigeminal lemniscus in the brain stem.

The Thalamus and Cortex

- Some second order neurons synapse on neurons in the ventral posterior nucleus of the thalamus (touch and pain signals remain separated), that in turn project to the somatosensory cortex.
- Other second order neurons synapse on neurons in the intralaminar nuclei of the thalamus, that in turn project to wider areas of the cerebral cortex.

The Regulation of Pain

Afferent Regulation

- Signals from mechanoreceptors can inhibit signals from nociceptors.

Descending Regulation

- Neurons in the periaqueductal gray of the midbrain synapse with neurons in the raphe nuclei of the brain stem, that in turn synapse with neurons in the dorsal horn
    - These neurons from the raphe nuclei appear to secrete serotonin.
- Injections of endorphins into the periaqueductal gray, raphe nuclei, or dorsal horn can produce analgesia.

Temperature

Thermoreceptors

- There are at least 6 distinct Trp channels that are sensitive to temperature.
- Cold receptors are associated with neurons with Aδ axons and C axons.
- Warm receptors are associated with neurons with C axons.

The Temperature Pathway

- The pathways for conveying temperature are nearly identical to those for conveying pain.