Medical Neuroscience | Tutorial Notes

Mechanosensation

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

NCC3. Genetically determined circuits are the foundation of the nervous system.

NCC7. The human brain endows us with a natural curiosity to understand how the world works.

LEARNING OBJECTIVES

After study of today's learning, the student will:

1. Identify and characterize the major sensory endings that mediate sensations elicited by touch, vibration, proprioception, and pain and temperature.
2. Characterize the mapping of the body (somatotopy) in the primary somatic sensory cortex.
3. Discuss the distribution of somatic sensory signals to higher-order processing centers in the parietal lobe, motor centers, emotional centers and memory centers in the brain.

TUTORIAL OUTLINE

I. Overview of somatic sensory systems[2]

   A. two major, modality-specific subsystems: **mechanosensation** and **pain & temperature**

      1. a specialized (phylogenetically newer) subsystem for the detection of mechanical stimuli (e.g., light, discriminative touch, vibration, pressure, movements of muscles and joints)

      2. a more primitive subsystem (phylogenetically older) for the detection of thermal and potentially harmful (painful or nociceptive) stimuli, and a more crude sense of touch

   B. basic functions of somatic sensory systems:

      1. identify shape and texture of objects (light touch)

      2. detect potentially harmful situations (**nociception** = "pain perception")

      3. monitor internal and external forces acting on the body

      4. contribute to neural representation of self (i.e., **proprioception** = "self-perception")

   C. basic organization of the somatic sensory systems:

[1] Visit **BrainFacts.org** for *Neuroscience Core Concepts* (©2012 Society for Neuroscience) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

[2] For completeness, pain & temperature systems are introduced here, but they will be considered in detail in a separate tutorial.

1. different types of peripheral receptors mediate the detection of different types (submodalities) of stimuli in each subsystem

2. two sets of pathways:

   a. for the post-cranial body (i.e., below the head and including the posterior portion of the head)

      i. mechanical stimuli: **dorsal-column medial lemniscal system**

      ii. pain and temperature: **anterolateral system** (and an unusual visceral pain pathway to be discussed later)

   b. for face (and anterior portion of the head)

      i. mechanical stimuli: pathway through the **principal (chief) sensory nucleus of the trigeminal complex**

      ii. pain and temperature: pathway through the **spinal nucleus of the trigeminal complex**

II. Mechanosensory processing

A. cutaneous and subcutaneous mechanosensory receptors

1. general organization and function

   a. first-order neurons are ganglion neurons (see **Figure 9.1**[3])

      (i) cell body in dorsal root ganglion or cranial nerve ganglion

      (ii) neuronal morphology = "pseudomonopolar"

      (iii) diverse endings of peripheral process (axon)

      (iv) central process synapses on second-order neurons in CNS

   b. functional categories

      (i) mechanoreceptors (touch, vibration, pressure)

      (ii) nociceptors (pain)

      (iii) thermoreceptors (temperature)

   c. morphological categories (see **Table 9.1**)

      (i) free nerve endings (pain, temperature)

         - supplied by very small diameter, 'unmyelinated' C fibers and lightly myelinated Aδ fibers

      (ii) encapsulated endings (touch, vibration, pressure)

         - very low threshold for activation

         - specializations of large diameter, myelinated fibers

         - differ in location in skin, the size of their receptive fields, and their density in different locations on the body surface

   d. mechanism of sensory transduction (see **Figure 9.2**)

[3] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

(i) physical deformation of receptor membranes open ion channels, and current (carried by sodium ions) flows into receptor ending

(ii) current depolarizes receptor membrane producing a receptor (or generator) potential

e. receptors specialized for tactile discrimination (see **Figures 9.5-6** & **Table 9.2**)

[in **Table 9.2** and **Figure 9.5**, for each of the four afferent systems described, learn the receptive field size (small vs. large), location, sensory function, effective stimuli, and adaptation rate (slow vs. rapid)]

a. **Meissner's corpuscles:** nerve endings encapsulated by Schwann cell lamellae

b. **Merkel disks**: saucer-shaped nerve endings that contact specialized cells (Merkel cells) between the dermal papillae

c. **Pacinian corpuscles**: axonal endings encapsulated by a large set of fluid-filled lamellae (like the layers of an onion)

d. **Ruffini corpuscles**: nerve endings surrounded by a spindle shaped capsule

2. receptors specialized for sensing body position (proprioceptors): "self-receptors" that respond to the mechanical forces arising in the body from the force of gravity and from active movements

a. **muscle spindles** (see **Figure 9.7A**)

(i) small number of intrafusal muscle fibers surrounded by a capsule of connective tissue in parallel with the extrafusal, striated muscle fibers

(ii) primary sensory endings from **group Ia** and **group II afferent fibers** encircle intrafusal fibers

(iii) both types of afferent fibers are stimulated by **stretch** applied to the muscle spindle

b. **Golgi tendon organs** (see **Figure 9.7B**)

(i) free nerve endings of **group Ib afferent** fibers that are woven into the matrix of collagen fibrils in tendons

(ii) sense the **force** (tension) generated by muscle contraction

c. **joint receptors**

(i) mechanosensory afferents distributed around joints

(ii) sense **joint motion**

B. ascending central pathways for somatic sensation (see accompanying tutorial)

III. Somatic sensory thalamus (see **Figure 9.10**)

A. the thalamic division that processes mechanosensory signals is the **ventral posterior complex**

1. receives ascending superficial mechanosensory and deeper proprioceptive information

2. divided into two main nuclei

a. **ventral posterior lateral nucleus**: receives information from the body (below the head) and posterior head

b. **ventral posterior medial nucleus**: receives information from the face (and anterior head)

IV. Somatic sensory cortex (see **Figure 9.10**)

A. **primary somatic sensory cortex**: region of the cerebral cortex that *first* receives the inputs from the (third-order) neurons in the ventral posterior complex of the thalamus

B. located in posterior bank of central sulcus (postcentral gyrus)

1. includes Brodmann's Areas 3a, 3b, 1 and 2

2. each subdivision of the primary somatic sensory cortex receives somewhat different submodalities of mechanosensory input

a. **Area 3a**: responds primarily to stimulation of "proper" proprioceptors (e.g., muscle spindles, joint receptors)

b. **Area 3b**: responds primarily to simple cutaneous stimuli applied to localized skin surfaces (e.g., discriminative touch)

c. Area 1: responds to more complex cutaneous stimuli, often involving stimulation of multiple digits in a certain direction

d. Area 2: responds to both complex tactile and proprioceptive stimuli

3. somatotopy in the primary somatic sensory cortex (see **Figure 9.11**)

a. each subdivision of the primary somatic sensory cortex contains a complete "map" of the contralateral sensory surface

b. certain body regions that are especially important for function (hands, face) are "over-represented"; i.e., receive disproportionate cortical allocation within the body map (the same is true at subcortical levels)

C. higher-order somatic sensory processing

1. each subdivision of the primary somatic sensory cortex sends axonal projections to the other subdivisions (see **Figure 9.12**)

2. these subdivisions, also project to several other important cortical regions:

a. a **secondary somatic sensory cortex** in the inferior parietal lobe, which itself contains an entire representation of the body surface

b. the **primary motor cortex** in the precentral gyrus (and other motor areas in the frontal lobe), where somatic sensory information is integrated to produce to appropriate motor behavior

c. regions of the superior parietal lobe where a "schema" of the somatic self is generated, based on the integration of somatic sensory and visual inputs (and probably other sensory inputs); this is what is sometimes referred to as the "body image"

3. higher-order somatic sensory areas project to limbic structures, such as the orbital-medial prefrontal cortex, the amygdala and the hippocampal formation, where

somatic sensory information is integrated with emotional signals (implicit processing) and memory traces (explicit processing)

STUDY QUESTION

Considering just the consequences for somatic sensation, what do you expect to result from a stroke involving the right middle cerebral artery?

A. anesthesia over the left side of the body (face, upper extremity, trunk, lower extremity)
B. anesthesia over the right side of the body (face, upper extremity, trunk, lower extremity)
C. anesthesia over the left side of the body below the face
D. anesthesia over the right side of the body below the face
E. anesthesia over the left side of the body below the trunk
F. anesthesia over the right side of the body below the trunk
G. anesthesia over the left side of the face and left arm, but sparing the left leg
H. anesthesia over the right side of the face and right arm, but sparing the right leg