SENSATION

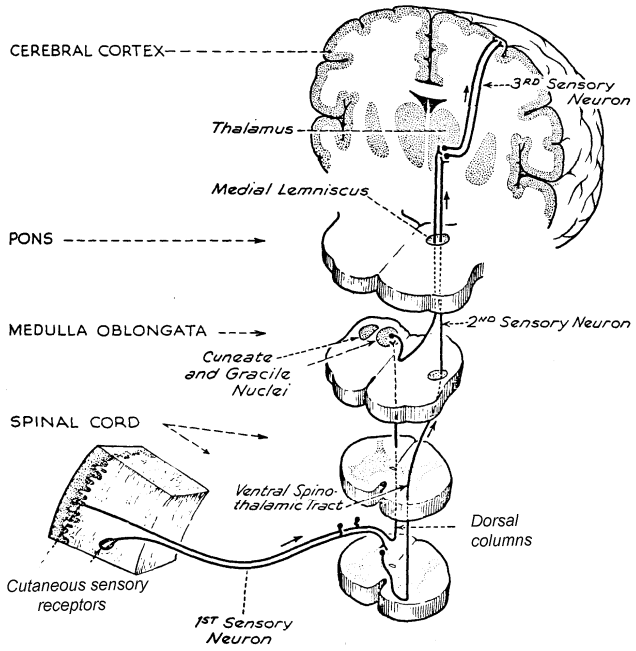
A. General Sequence

1. When stimulated, an afferent nerve ending (sensory receptor) generates one or more *action potentials* (1st order or primary afferent neuron)

2. These action potentials are conducted into the *Central Nervous System* (spinal cord and brain), where they excite adjacent nerve cells (2nd order, 3rd order, etc. neurons)

3. By this mechanism, excitation eventually reaches specialized regions of the *cerebral cortex* where conscious sensation occurs*;* sensory pathways have a minimum of one-three synapses (two-four neurons), depending on modality

4. If this sequence is interrupted, conscious sensation is lost (*anesthesia*)



DIMENSIONS OF SENSATION

A. Modality

1. Define: quality of sensation

2. Basis: receptor stimulated and its adequate stimulus

   a. many types of stimuli can excite a given sensory receptor if sufficiently strong, but in normal circumstances, only a single type of stimulus causes excitation. This type is termed the receptor's *adequate stimulus*.

   b. the sensation evoked by stimulation of a receptor or its pathway is sensed as being caused by the receptor's adequate stimulus, no matter what the actual stimulus ("Doctrine of Specific Nerve Energies")

DIMENSIONS OF SENSATION

A. Modality (continued)

	ADEQUATE STIMULUS	**EXAMPLES**
Mechanoreceptor	mechanical distortion	touch, pressure
Chemoreceptor	chemical concentration	taste, smell, oxygen receptor
Thermoreceptor	temperature	warm, cold
Photoreceptor	photons	visible light
Nociceptor	noxious	painful stimuli
Proprioceptor (mechano-)	*body position, muscle tone*	*joint position, tendon force*

B. Intensity and Time Course

1. Determined by

   a. Firing frequency of individual sensory nerve fibers

   b. Number of sensory fibers activated simultaneously -- r*ecruitment*, which depends on

      1) distribution of sensory ending thresholds
      2) relative locations of stimulus and endings

   c. Adaptation: decrement in sensation intensity with a maintained stimulus

   d. Change in receptor sensitivity due to local environment (e.g. *sensitization*)

   e. Interaction at CNS synapses between ascending pathways or between ascending and descending pathways (e.g. *gating* or *modulation*)

C. Location

1. Basis: location of the sensory receptor and anatomical (topographic) organization of sensory pathways

2. Law of Projection: sensation is sensed as arising from (projected to) the receptor's receptive field even when it arises elsewhere (e.g. phantom limb)

3. Receptive Field: region from which application of a normal stimulus causes the afferent ending to respond

4. Acuity -- the precision of stimulus localization or the ability to distinguish fine details -- depends upon

   a. size of the receptive field (small field $\Rightarrow$ better acuity)
   b. innervation density (higher density $\Rightarrow$ better acuity)
   c. convergence along CNS pathways (less convergence $\Rightarrow$ better acuity)
   d. lateral or surround inhibition (increases acuity; discussed later)

D. Affect

1. Define: pleasantness (positive affect) or unpleasantness (negative affect) of a sensation

2. Separate dimension: can become disassociated (*dissociation*) from other aspects of sensation

3. Basis: stimulation of specific regions in the CNS located particularly in the midbrain and the hypothalamus

SOMATIC SENSATION INTRODUCTION

A. Origin of Somatic Sensation

Afferent endings widely distributed in skin, muscles, tendons, bones, joints, connective tissue, etc.

B. General Characteristics

1. Relatively simple endings (compared with special senses)

2. Several morphologically different types of endings

3. Enter the CNS via spinal afferents and certain cranial nerves

4. General classification
   a. "Discriminative": encapsulated endings innervated by larger myelinated axons; greater sensitivity; more precise localization
   b. "Crude": free nerve endings innervated by smaller myelinated or unmyelinated axons; less sensitive; less precise localization

C. Modalities (major)

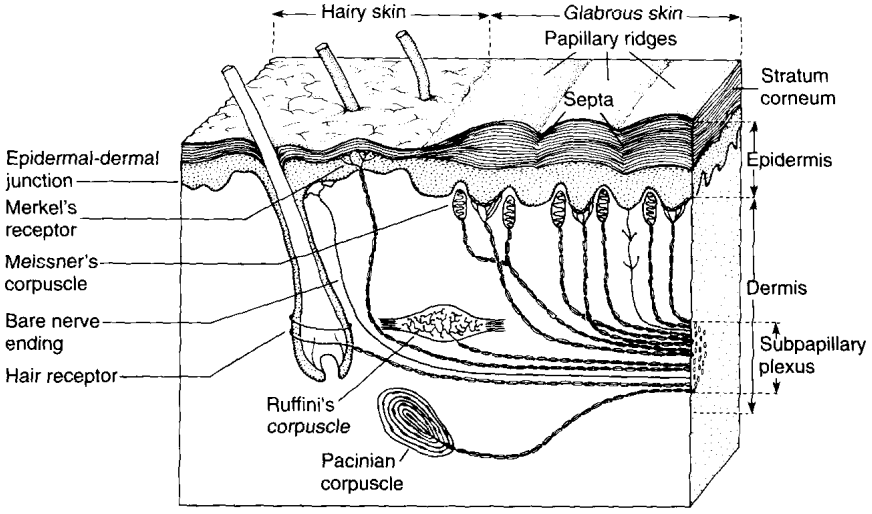
1. Mechanosensation: touch, pressure, vibration, flutter, proprioception

2. Thermal: warm, cold

3. Pain and Itch

MECHANOSENSATION

A. Afferent Endings and Fibers



	Fibers	Adequate Stimulus	Field Size	Adaptation	Sensation
Merkle cell	Aβ	Skin indentation	*small*	*slow*	Touch-pressure
Meissner corpuscle	Aβ	Vibration	*small*	*rapid*	Flutter, contact
Ruffini ending	Aβ	Skin indentation	*large*	*slow*	Touch
Pacinian corpuscle	Aβ	Vibration	*large*	*very rapid*	Vibration
Hair follicle	Aβ	Hair bending	small	rapid	Touch, contact
Free ending	Aδ	Skin indentation	large	rapid	Contact (coarse)
Muscle spindle	Ia, II	Muscle length		rapid, slow	Proprioception
Golgi tendon organ	Ib	Muscle tension		slow	Proprioception
Joint receptors	small	Joint angle		rapid	Proprioception

MECHANOSENSATION (continued)

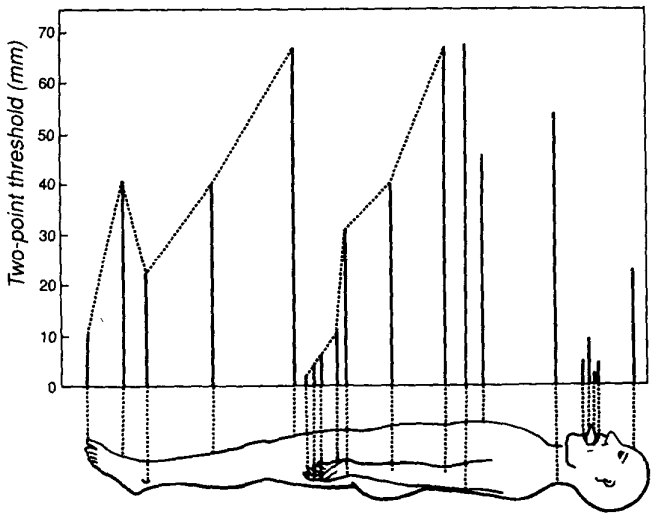
B. Characteristics

1. Encapsulated and hair follicle receptors are more sensitive and are innervated by larger fibers

2. Superficial and hair follicle receptors tend to have smaller receptive fields

3. Receptors are unevenly distributed, which accounts in part for the difference in sensitivity and acuity in various body regions

   Note: Two Point Threshold: the smallest distance between two adjacent stimuli that can be distinguished as separate



4. The more rapid the adaptation, the more rapidly changing must the stimulus be in order to evoke a response

5. The consequence of the variety of endings is that the CNS is presented with information not only about touch and pressure but also about texture and movement

THERMAL SENSATION

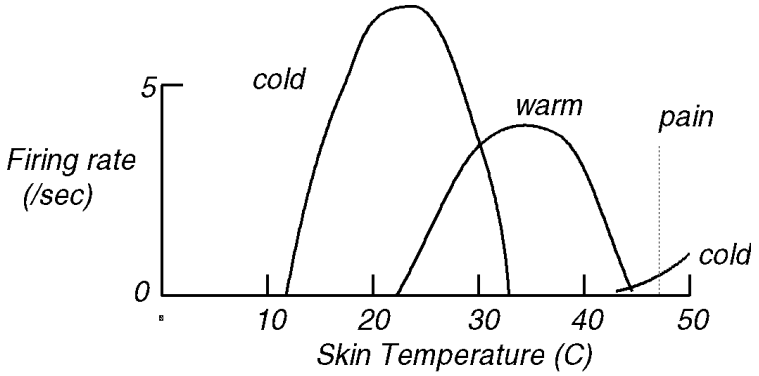
A. Afferent Endings and Fibers

	Fibers	Adequate Stimulus	Adaptation	Sensation
Free nerve endings	Aδ	Cool skin (15-35 C)	intermediate	Cold
Free nerve endings	C	Warm skin (25-45 C)	intermediate	Warm

B. Characteristics

1. Each receptor population has an optimal temperature range for its steady state response

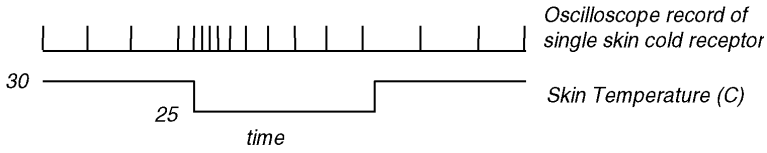
Typical warm and cold thermal endings



Note: temperature sensed depends on the relative firing rates of the two receptor populations

Note: thermal neutral (comfort): skin temperature approximately 30 C (86 F)

2. Each receptor type adapts partially and has an appreciable phasic response; a cold receptor is stimulated by a falling temperature (within its sensitive temperature range) and inhibited by a rising temperature; a warm receptor is stimulated by rising temperature and inhibited by a falling temperature



3. Thermoreceptors resulting in temperature sensation are limited almost exclusively to the skin, although there are additional thermoreceptors in the hypothalamus (related to temperature regulation) and spinal cord (function unknown)

4. Thermal sensation is poorly localized (characteristic of modalities whose primary afferents are small diameter fibers)

5. At sufficiently high temperature, some cold receptors begin to discharge ("paradoxical cold response"), which confuses temperature perception; at higher temperatures, nociceptor discharge masks thermosensation

Note: thermal pain (& tissue damage) threshold approx. 45 C (113 F)

6. At sufficiently low temperature, thermal sensation (along with other sensation) is lost

PAIN AND ITCH

A. Afferent Endings and Fibers (to be covered later)

	Fibers	Adequate Stimulus	Adaptation	Sensation
Free ending	Aδ	Noxious	slow	Pricking pain
Free ending	C	Noxious	slow	Burning pain
Free ending	C	Pruritogenic	slow	Itch

VISCERAL SENSATION

A Afferent endings and fibers

1. Small fibers: Aδ and C

2. Endings: not well characterized

Note: sensory fibers travel with visceral motor (autonomic) fibers but enter spinal cord via dorsal roots along with somatosensory and proprioceptive afferents

B Sensations

1. Pain (e.g. stomach ache, heartburn, appendicitis)

2. Mechanosensation ("fullness")

3. Smooth muscle tension (e.g. bladder "urge")

4. Several visceral sensations are poorly understood, e.g.

a. dyspnea (conscious sensation of breathing difficulty)
b. satiety (opposite of hunger)

SOMATOSENSORY PATHWAYS

A. Peripheral Nerve

1. Receptive field: sensory endings innervated by afferent axons in nerve

2. Results of nerve section or degeneration

a. anesthesia of zone innervated only by the nerve that was cut

b. if possible, regeneration of peripheral segments of severed axons and re-establishment of normal sensation

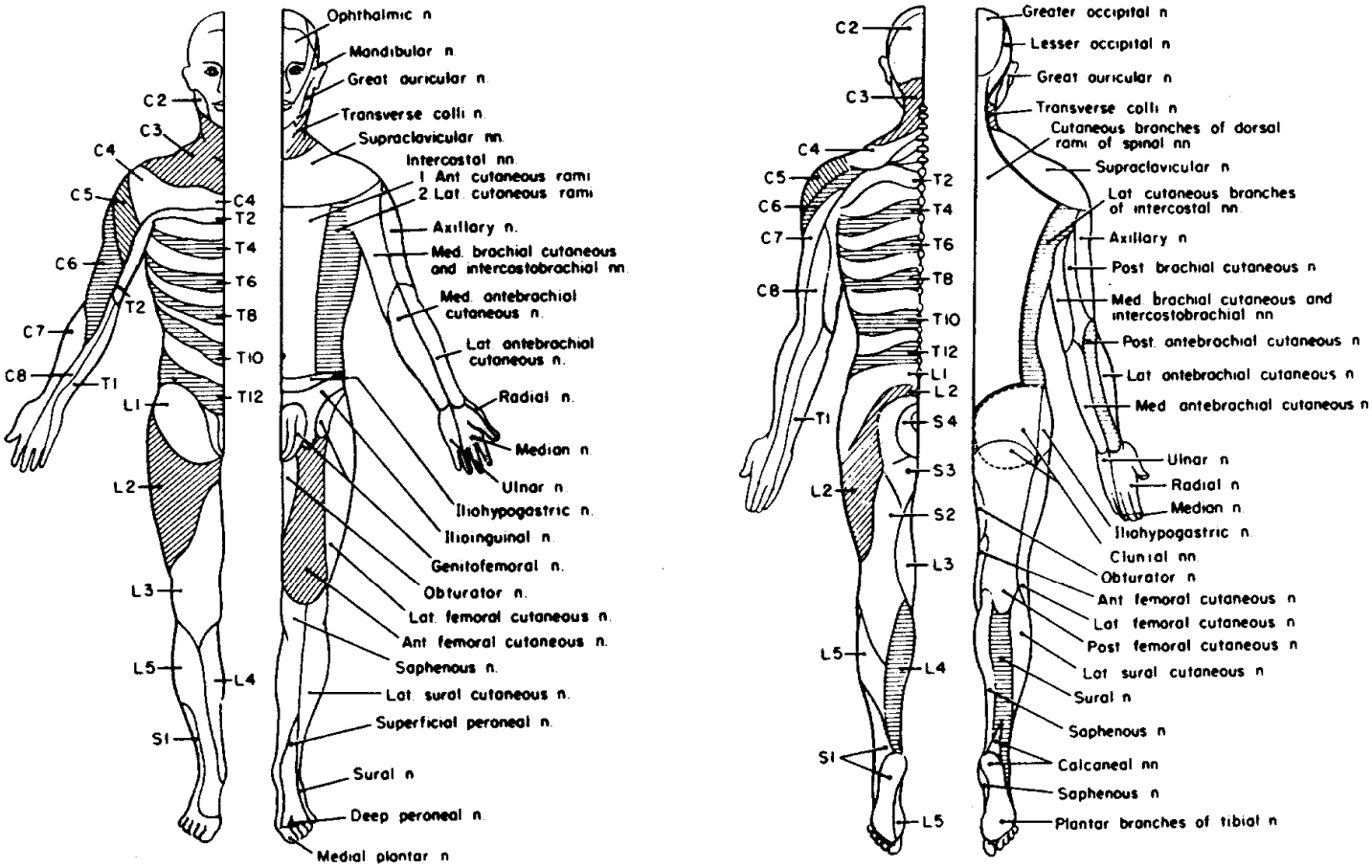
Note: Regeneration of severed peripheral nerve

a. peripheral segment degenerates but central part remains intact if the neuron soma remains vital

b. central cut end sends out sprouts

c. if the sprouts encounter the Schwann cell sheath of the degenerating peripheral segment, the sprouts enter the sheath and following the course of the damaged axons reinnervate the denervated tissue (growth rate 1-2 mm/day)

SOMATOSENSORY PATHWAYS (continued)



B. Spinal Dorsal Root

1. Cutaneous receptive field: <u>dermatome</u>

   a. define: cutaneous region innervated by the axons of a single dorsal root

   b. do not correspond to peripheral nerve receptive fields

   c. note that adjacent dermatomes overlap

2. Deep and visceral sensory axons join with cutaneous axons to form dorsal root

SOMATOSENSORY PATHWAYS (continued)

C. Ascending Pathways (see figure, page 1)

1. Dorsal column system

a. subserves sensations mediated by 1st order rapidly conducting axons (larger myelinated axons): fine, discriminative touch; flutter and vibration; proprioception, particularly joint receptors

b. 1st order neuron: ascends in the ipsilateral (same side) dorsal column of the spinal cord and synapses in the medulla

c. 2nd order neuron: crosses to the contralateral side in the medulla and ascends to the thalamus

d. 3rd order neuron: ascends from the thalamus to the sensory cerebral cortex

2. Anterolateral system

a. subserves sensations mediated by 1st order more slowly conducting axons (smaller myelinated and unmyelinated axons): crude touch, thermal sensation, pain (& itch)

b. 1st order neuron: synapses in the dorsal horn

c. 2nd order neuron: crosses to the contralateral side in the spinal cord and ascends in the anterolateral tracts (spinothalamic tracts)

d. 3rd order neuron: ascends from the thalamus to the sensory cerebral cortex

SOMATOSENSORY CEREBRAL CORTEX (Primary Somatosensory Cortex: S1)

A. Occupies postcentral gyrus on parietal cortex

B. Organized by somatotopically (“homunculus” map)

1. experimental evidence

a. electrical stimulation of S1 can elicit sensation projected to (sensed as originating from) a discrete body area
b. electrical activity from neurons in S1 can be recorded only for discrete receptive fields
c. lesions of S1 lead to corresponding sensory deficits
d. imaging techniques based on scans (PET, NMR, CAT) for tracer uptake or metabolic activity

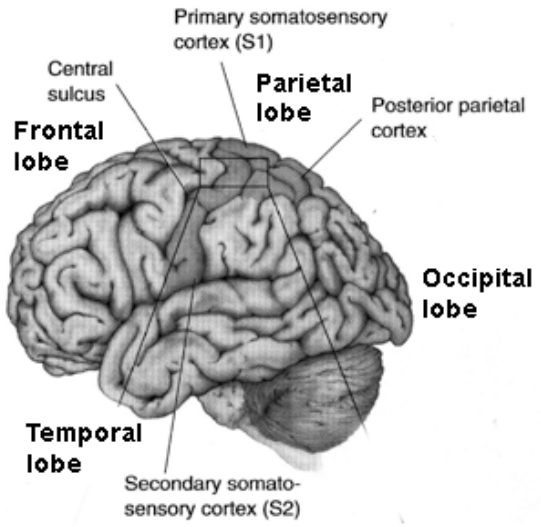
2. features

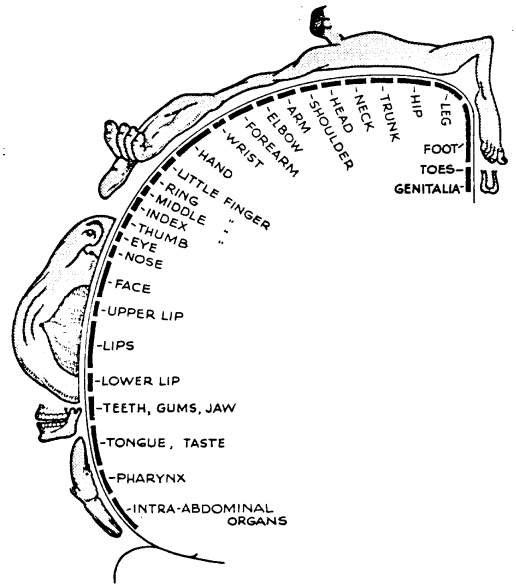
a. contralateral representation

b. map is distorted, with area on cortex more-or-less proportional to innervation density and sensory acuity of body surface

c. essential for normal conscious sensation

SOMATOSENSORY CEREBRAL CORTEX (continued)





C. Cortical columns of S-I

a. consist of groups of several hundred neurons oriented perpendicularly to the cortical surface and including the six layers of the cortical gray (I = superficial, VI = deep)

b. forms the functional unit of the somatosensory cortex; the cells in the layers of each column are interconnected

c. output from each column goes to
   1. adjacent columns
   2. adjacent somatosensory cortex regions
   3. more distant regions (e.g. association cortex)
   4. contralateral cortex
   5. out of cortex to thalamus and brain stem