Human Phys PCB4701

Sensory Physiology
Fox Chapter 10 part 1
Somatosenation

Principles of Sensory Systems

Stimulus Modality
touch, pressure, vibration, chemicals, light

Neural Response
Rate of firing proportional to stimulus strength
Phasic vs. Tonic firing patterns

Sensory Receptor Cells
Different for each sensory modality.

Receptive Fields
The range of the stimulus (e.g. a particular sound frequency) or the area covered by the stimulus (e.g. a particular spot on the skin) that causes a sensory neuron to respond.

Central Representation
How does the peripheral sensory input get mapped onto the cerebral cortex?

Central Feature Extraction
From the raw input of the peripheral sensory neurons, the cortex extracts more complex features (ultimately resulting in cognition).

Table 10.1

Table 10.1 | Classification of Receptors Based on Their Normal (or "Adequate") Stimulus

Receptor	Normal Stimulus	Mechanisms	Examples
Mechanoreceptors	Mechanical force	Deforms cell membranes of sensory dendrites or deforms hair cells that activate sensory nerve endings	Cutaneous touch and pressure receptors; vestibular apparatus and cochlea
Pain receptors	Tissue damage	Damaged tissues release chemicals that excite sensory endings	Cutaneous pain receptors
Chemoreceptors	Dissolved chemicals	Chemical interaction affects ionic permeability of sensory cells	Smell and taste (exteroceptors) osmoreceptors and carotid body chemoreceptors (interoceptors)
Photoreceptors	Light	Photochemical reaction affects ionic permeability of receptor cell	Rods and cones in retina of eye

Receptor	Normal Stimulus	Examples
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Photoreceptors	Light	Rods and cones in retina of eye

Figure 10.2

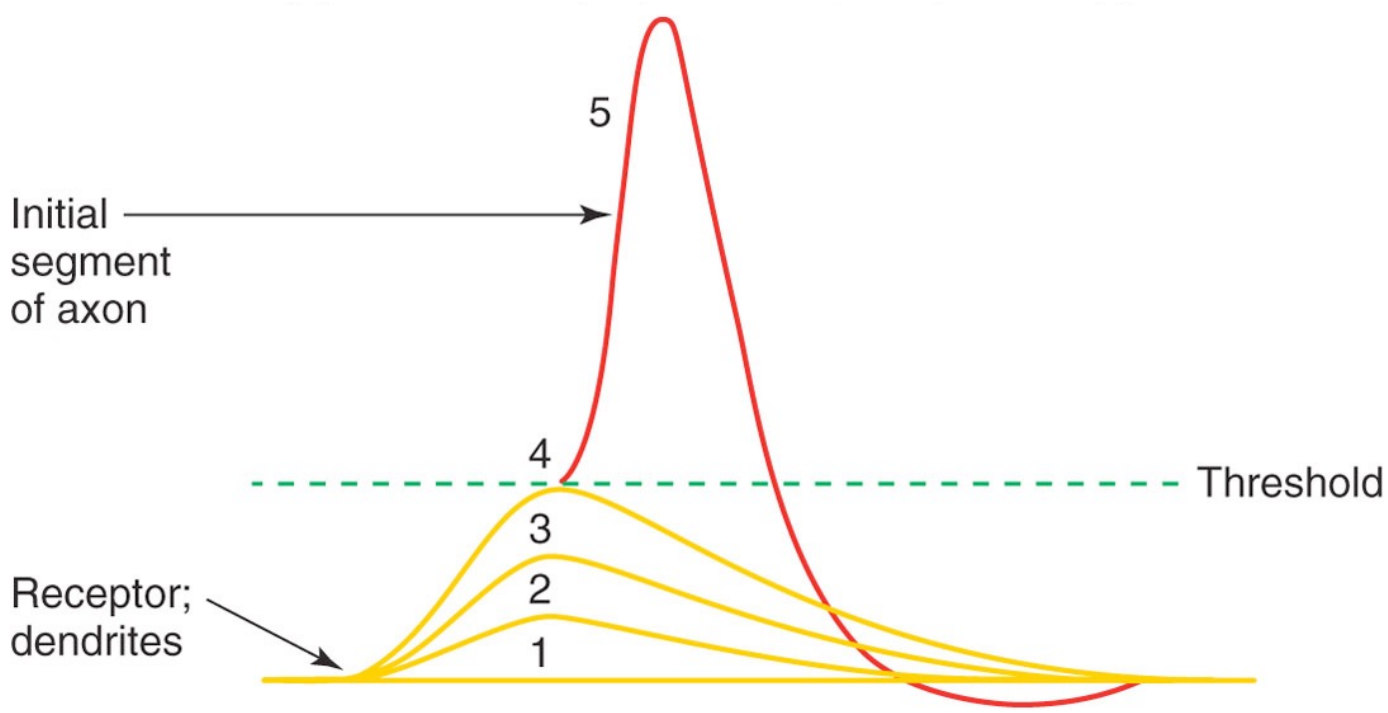

5
Initial
segment
of axon
4
Threshold
3
2
Receptor;
dendrites
1

Figure 10.3

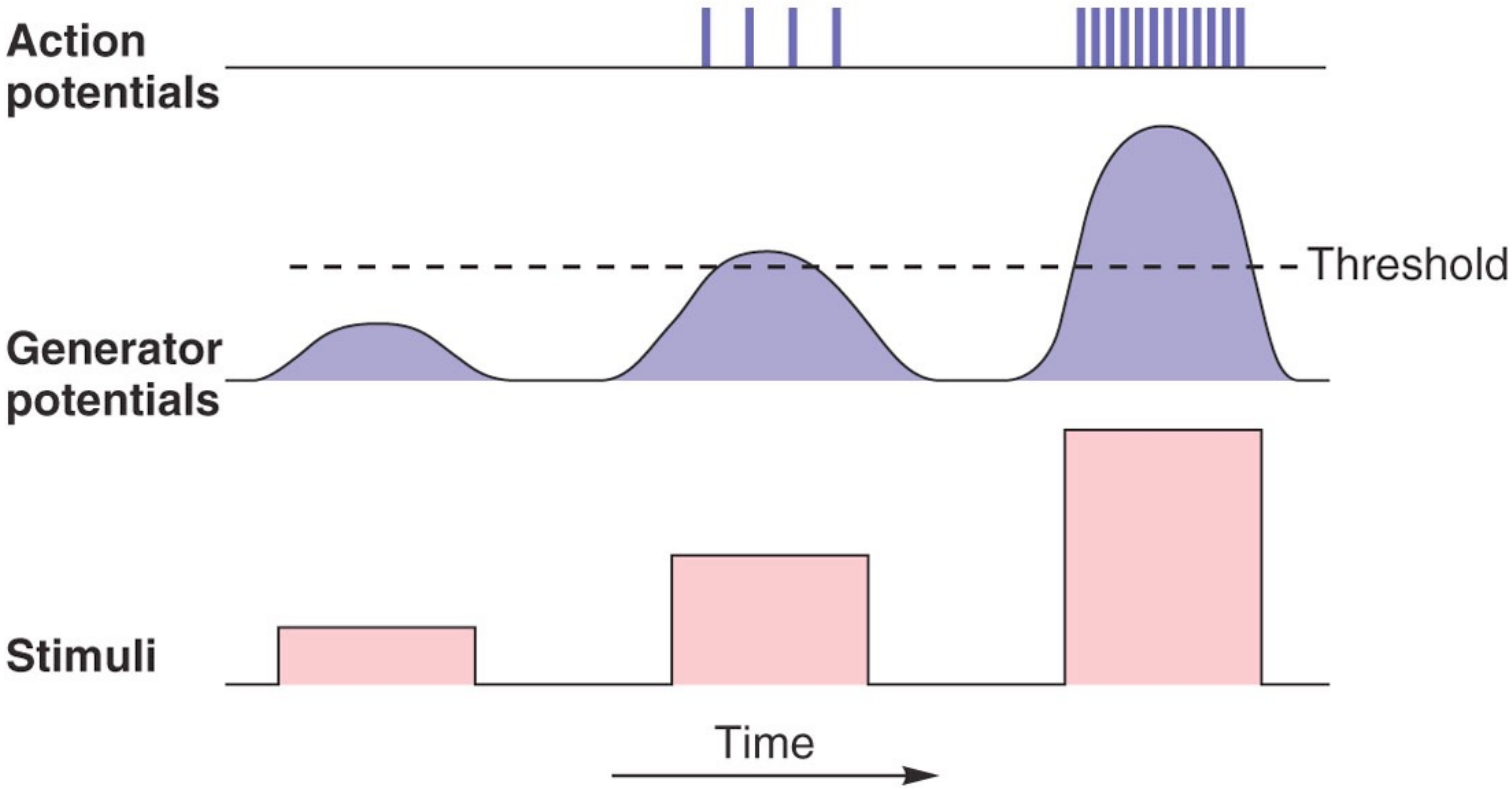
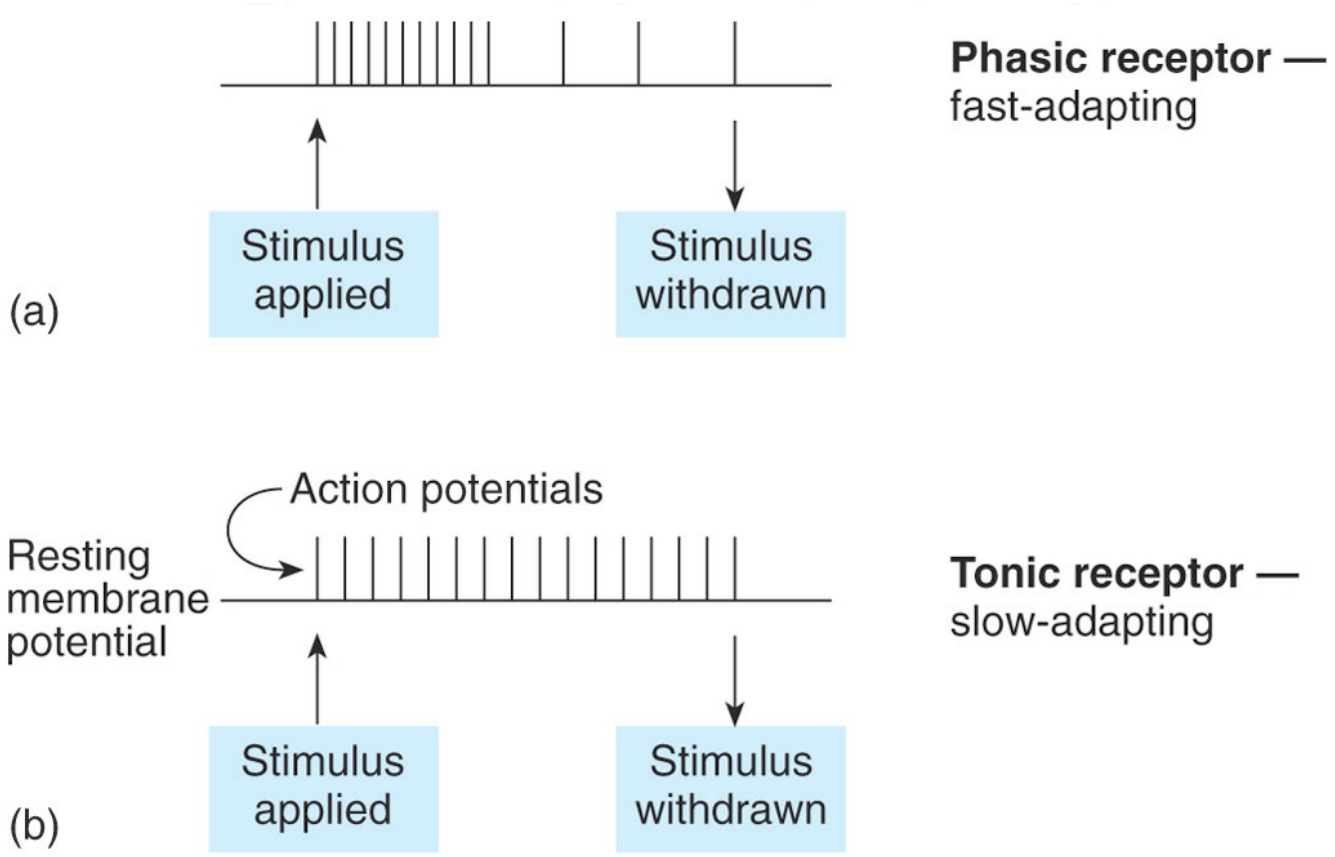

Action potentials
Threshold
Generator potentials
Stimuli
Time

Figure 10.1


Phasic receptor —
fast-adapting
Stimulus applied
Stimulus withdrawn
(a)
Action potentials
Resting membrane potential
Tonic receptor —
slow-adapting
Stimulus applied
Stimulus withdrawn
(b)

Somatosensation

Mechanoreceptors that respond to touch/pressure on the surface of the body.

Sensory nerve responds propotional to pressure

4 types of mechanoreceptors:

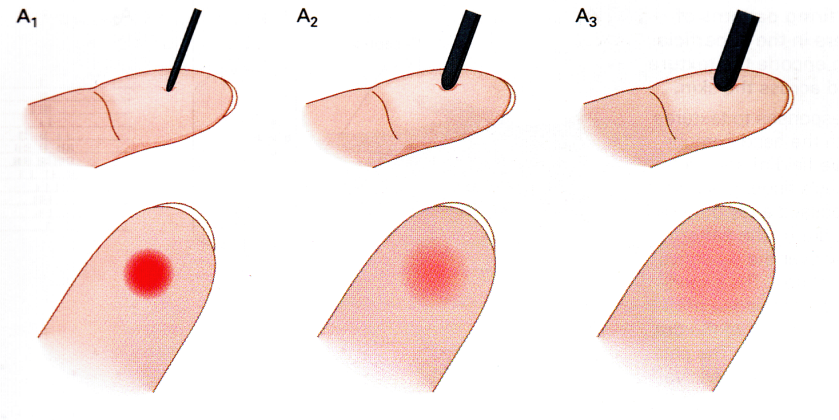
Meissner corpuscles & **Merkel** discs - cutaneous light touch with high resolution.

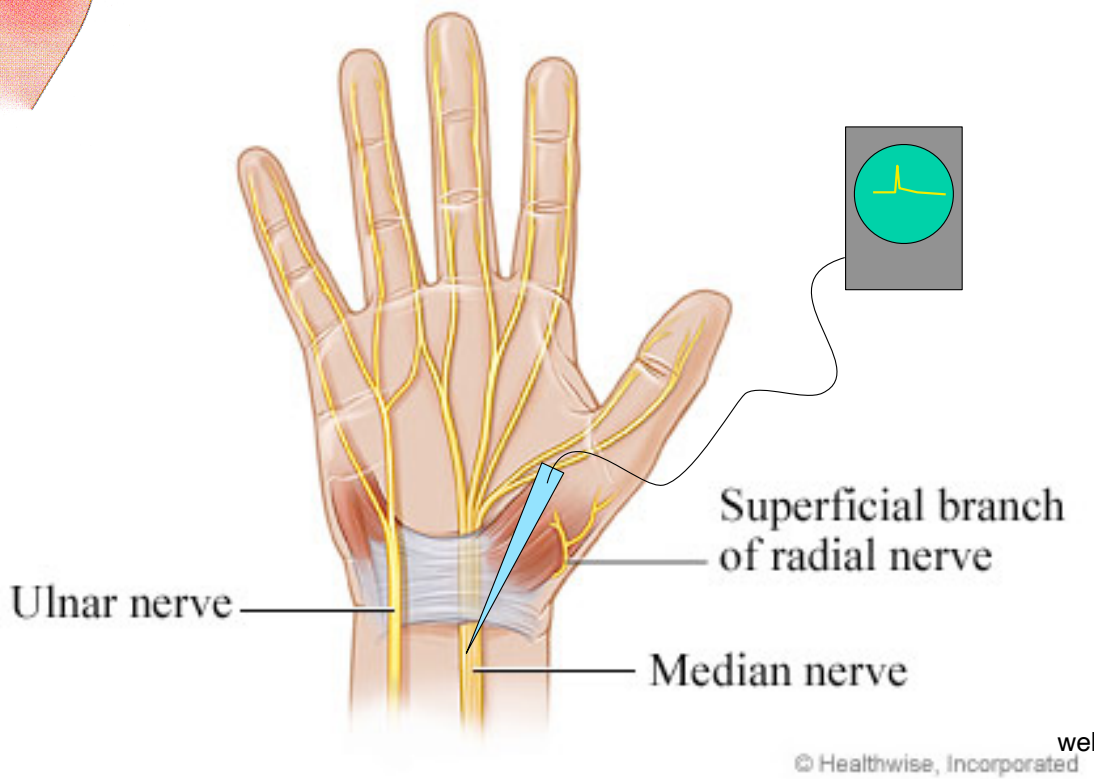
Pacinian corpuscles & **Ruffini** endings - deep receptors responding to stronger force with less acuity.

Meissner and Pacinian are **rapidly adapting** (phasic response) Merkel and Ruffini are **slowly adapting** (tonic response).

(also free nerve endings that respond to temperature, painful stimuli)

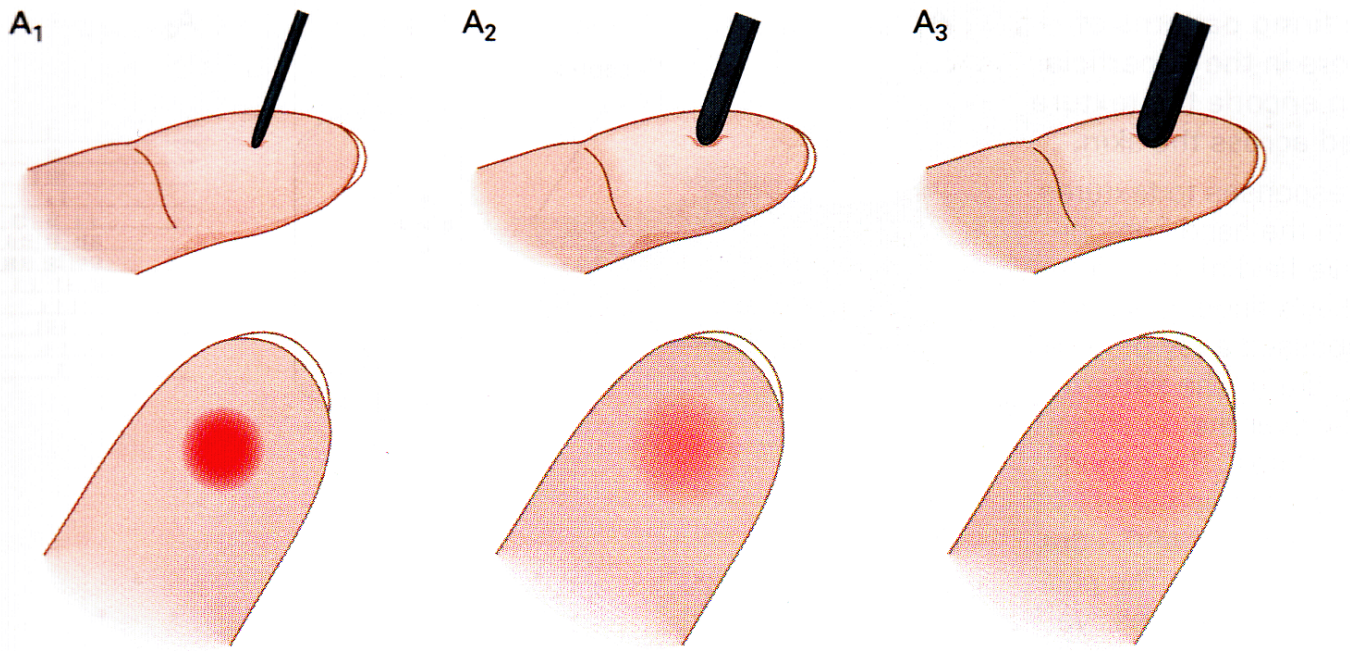
Receptive fields map to specific area on the body. **Density** of receptive fields varies across the body (lips, fingers have highest density so most sensitive).
Two-touch discrimination maps out receptive field density.


A1
A2
A3


Superficial branch
of radial nerve
Ulnar nerve
Median nerve
© Healthwise, Incorporated

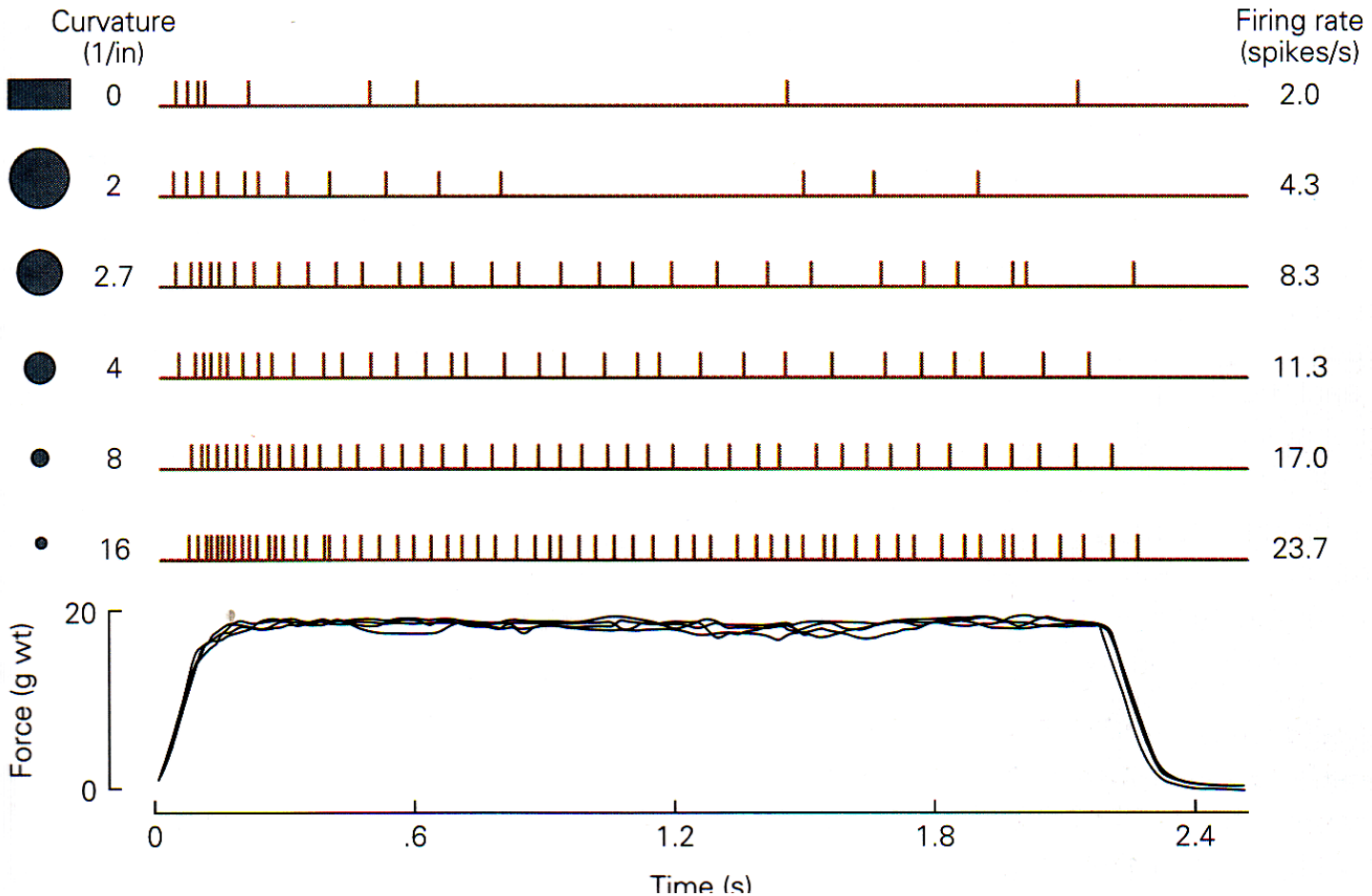
webmd.com

Receptive field response to pressure



Small point causes intense pressure over small area
Large point spreads pressure over wider area

Firing Rate: response to pressure



How mechanoreceptors work

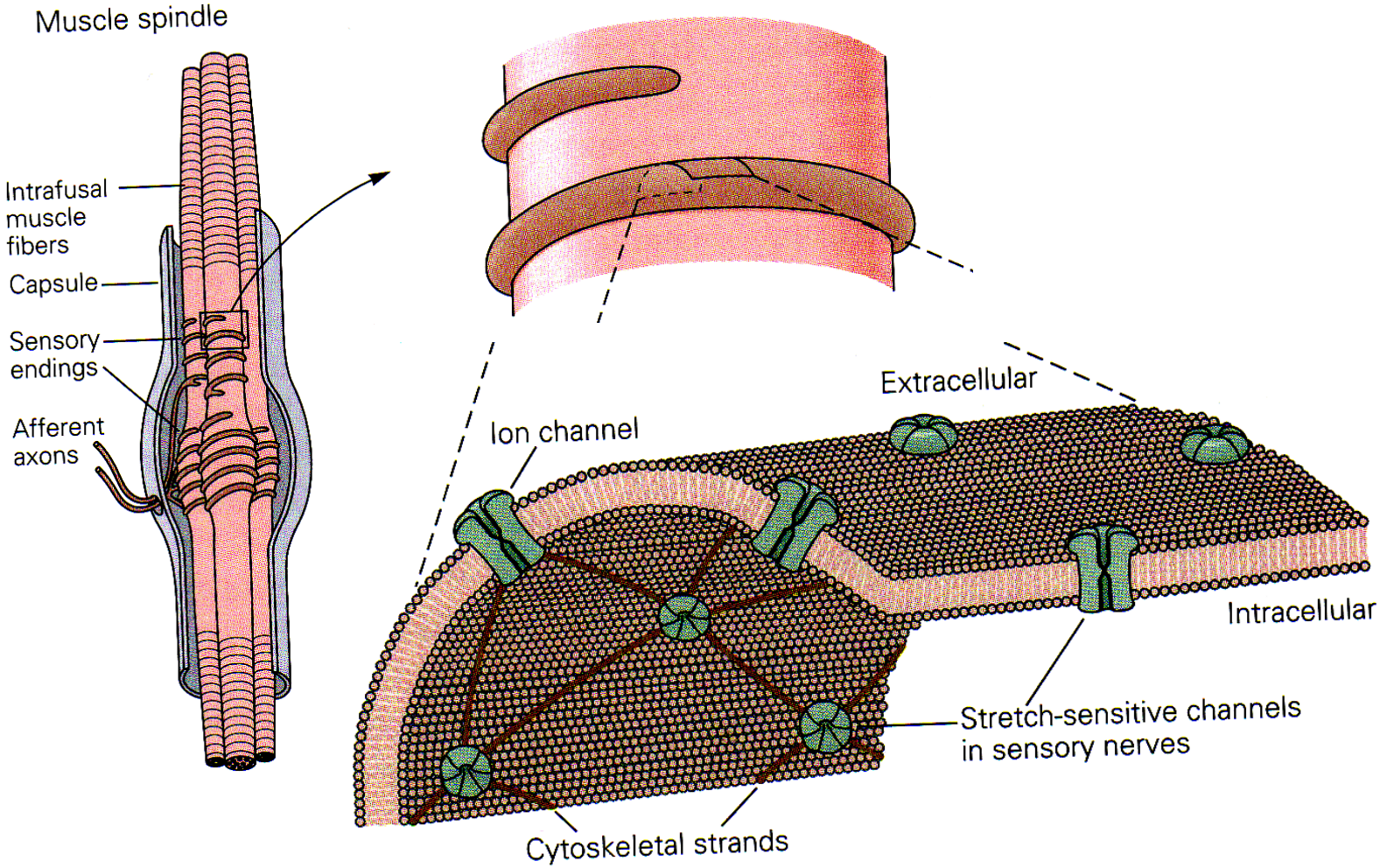
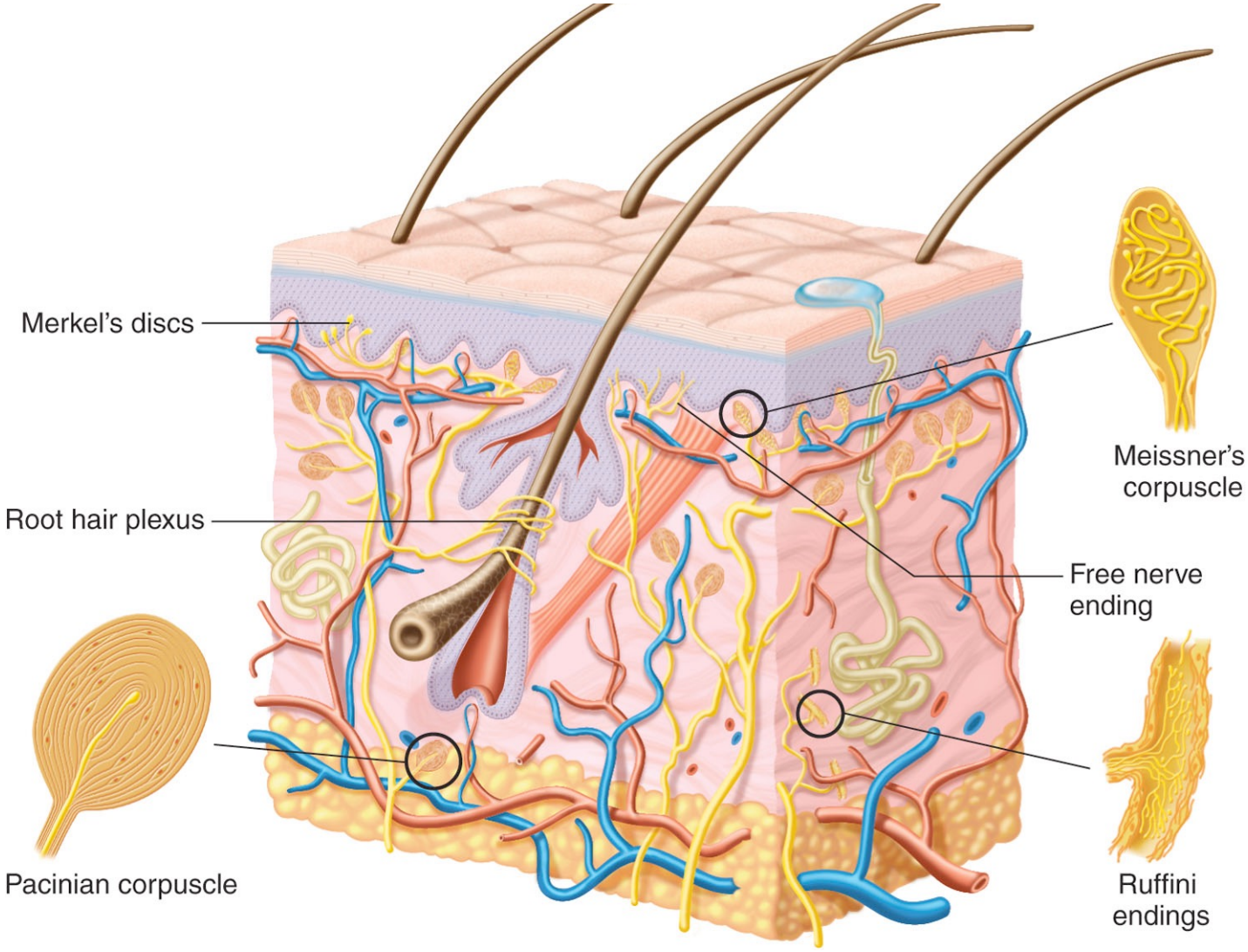


Table 10.2

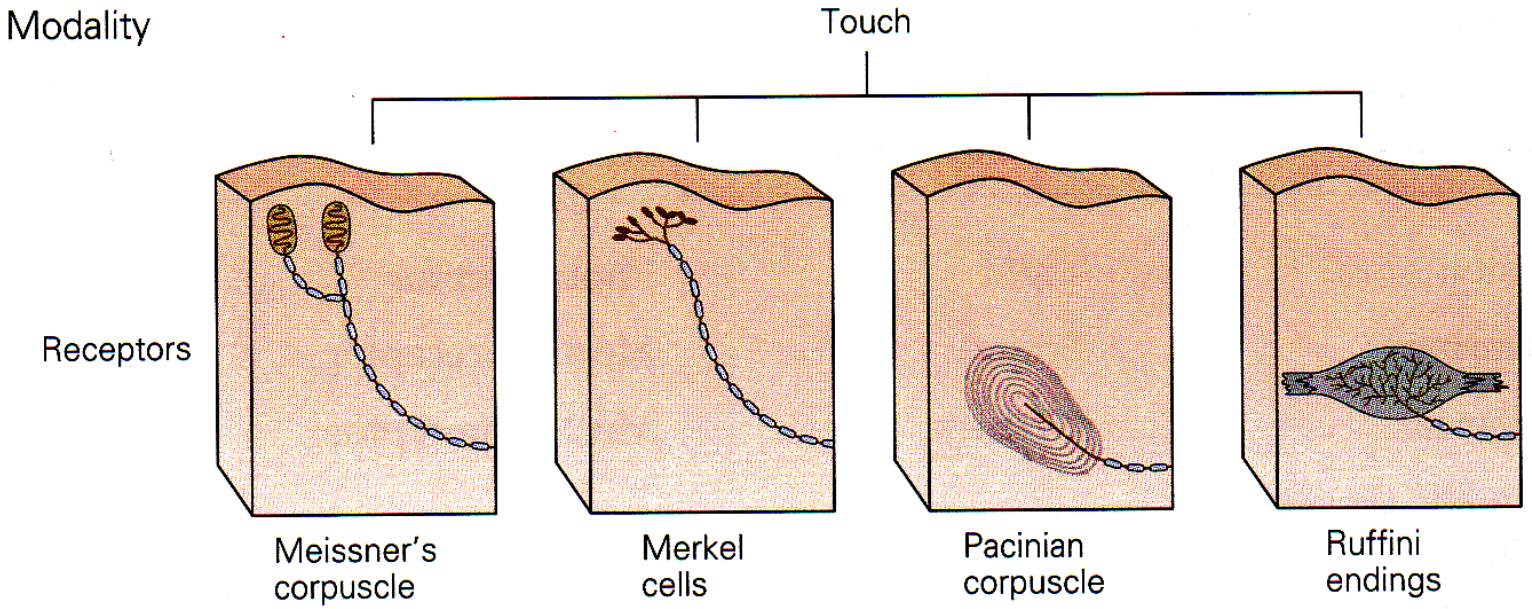
Table 10.2 | Cutaneous Receptors

Receptor	Structure	Sensation	Location
Free nerve endings	Unmyelinated dendrites of sensory neurons	Light touch; hot; cold; nociception (pain)	Around hair follicles; thr skin
Merkel's discs	Expanded dendritic endings	Sustained touch and pressure	Base of epidermis (strat
Ruffini corpuscles (endings)	Enlarged dendritic endings with open, elongated capsule	Sustained pressure	Deep in dermis and hyp
Meissner's corpuscles	Dendrites encapsulated in connective tissue	Changes in texture; slow vibrations	Upper dermis (papillary
Pacinian corpuscles	Dendrites encapsulated by concentric lamellae of connective tissue structures	Deep pressure; fast vibrations	Deep in dermis

Figure 10.4


Merkel's discs
Root hair plexus
Pacinian corpuscle
Meissner's corpuscle
Free nerve ending
Ruffini endings

4 Types of Mechanoreceptors



All respond to touch, but have different:

anatomy

receptive fields

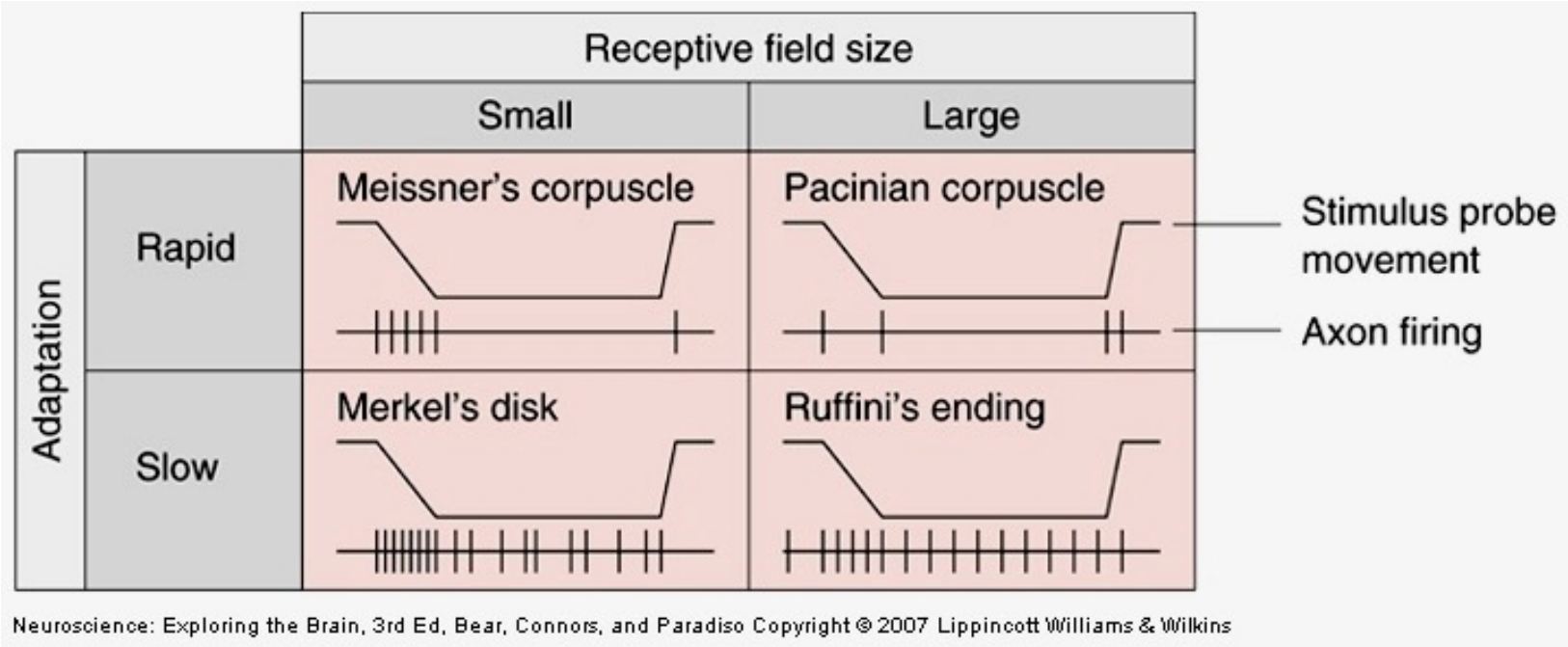
intensity/time response characteristics

which make each receptor respond best to particular stimuli

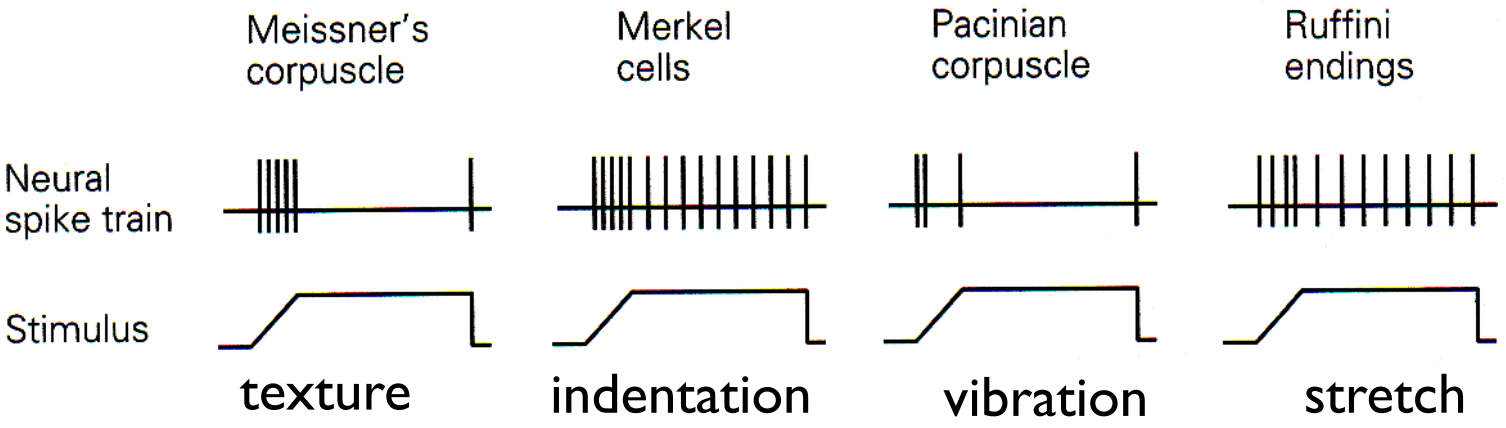
4 Mechanoreceptors

Meissner & Merkel - cutaneous light touch with high resolution.

Pacinian & Ruffini corpuscles - deep receptors responding to stronger force with less acuity.



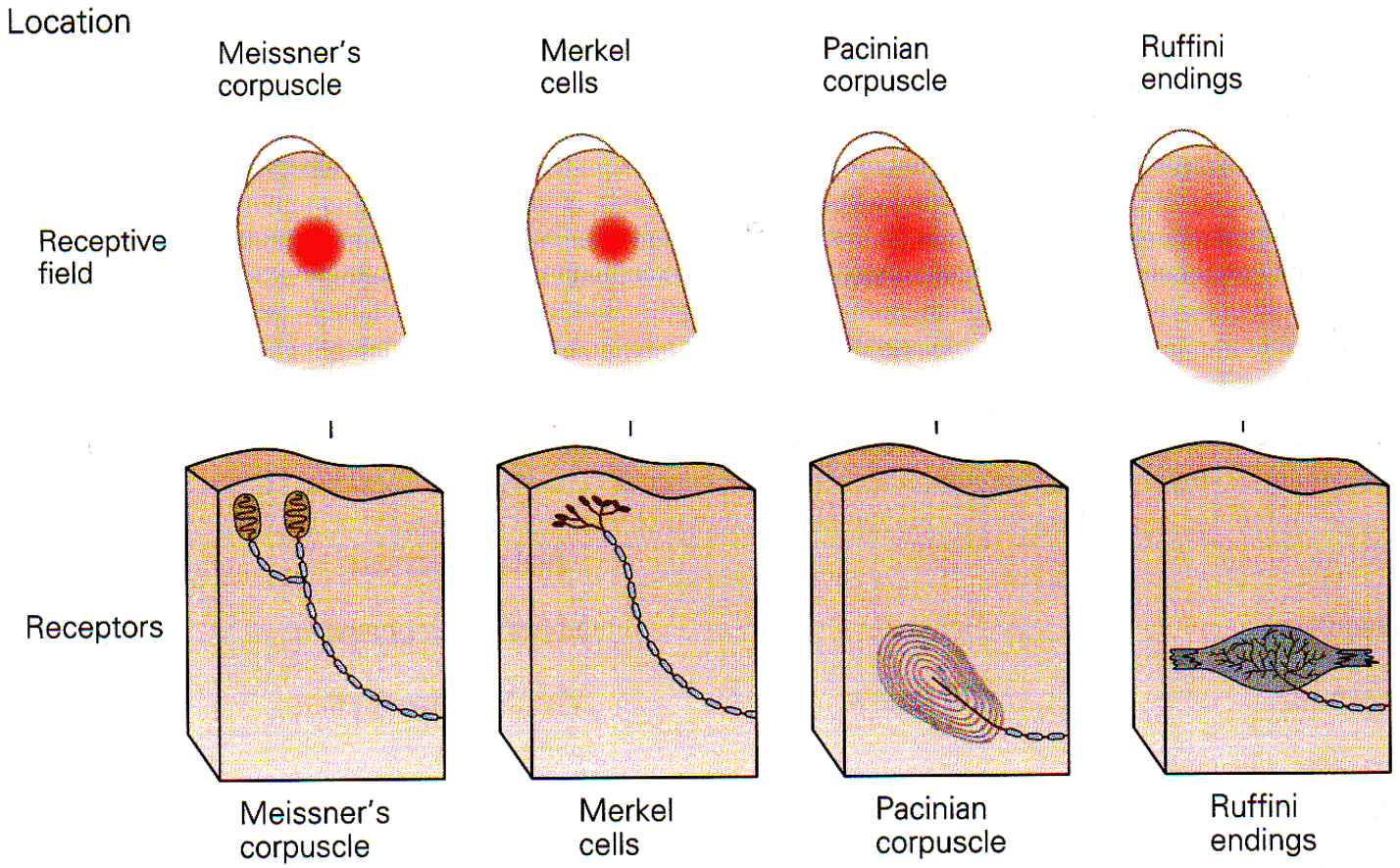
Intensity & timing of response characteristics: slowly-adapting and rapidly-adapting receptors



Rapidly adapting -- respond best to onset & offset of stimulus
(or rapidly changing stimulus -- edge or slope detector)

Slowly adapting -- continue to respond to continuous stimulus

Size of receptive field varies among mechanoreceptors



Receptive Field of a Somatosensory Neuron

Two-point Touch determines density of receptive fields

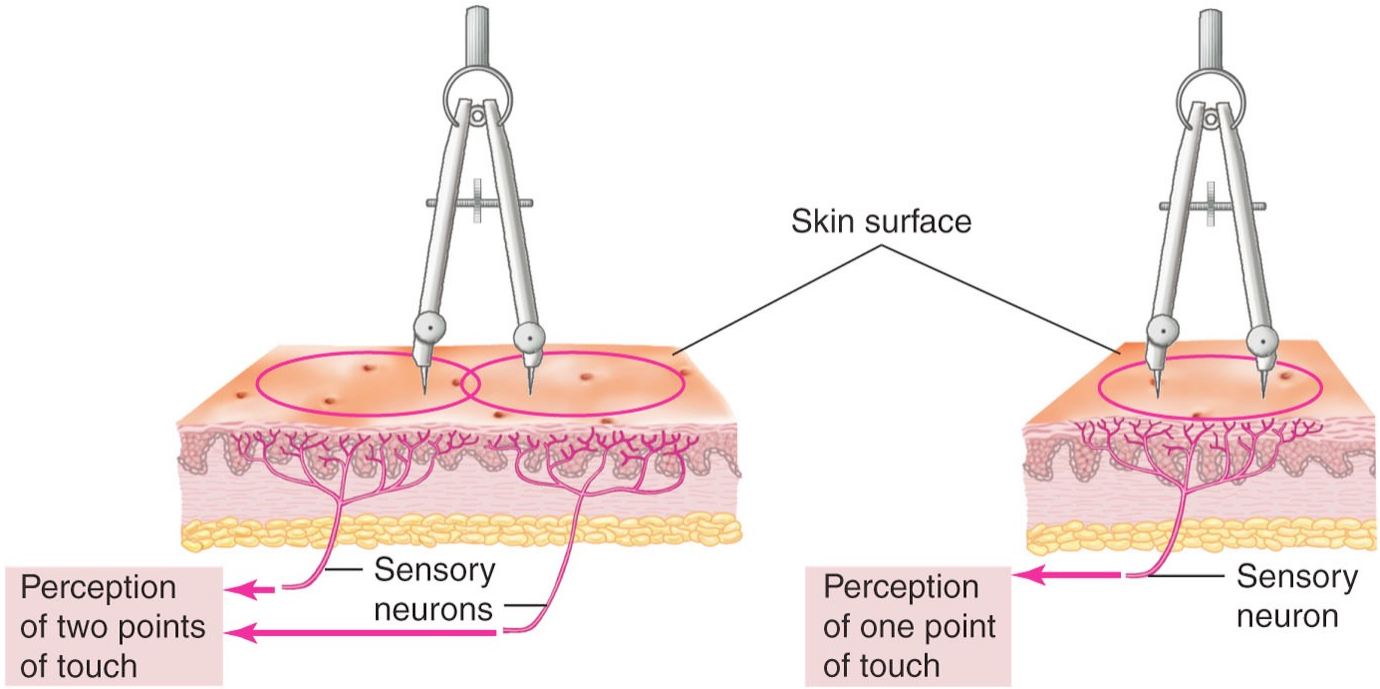


Figure 10.5

Density of receptors determines somatosensory acuity

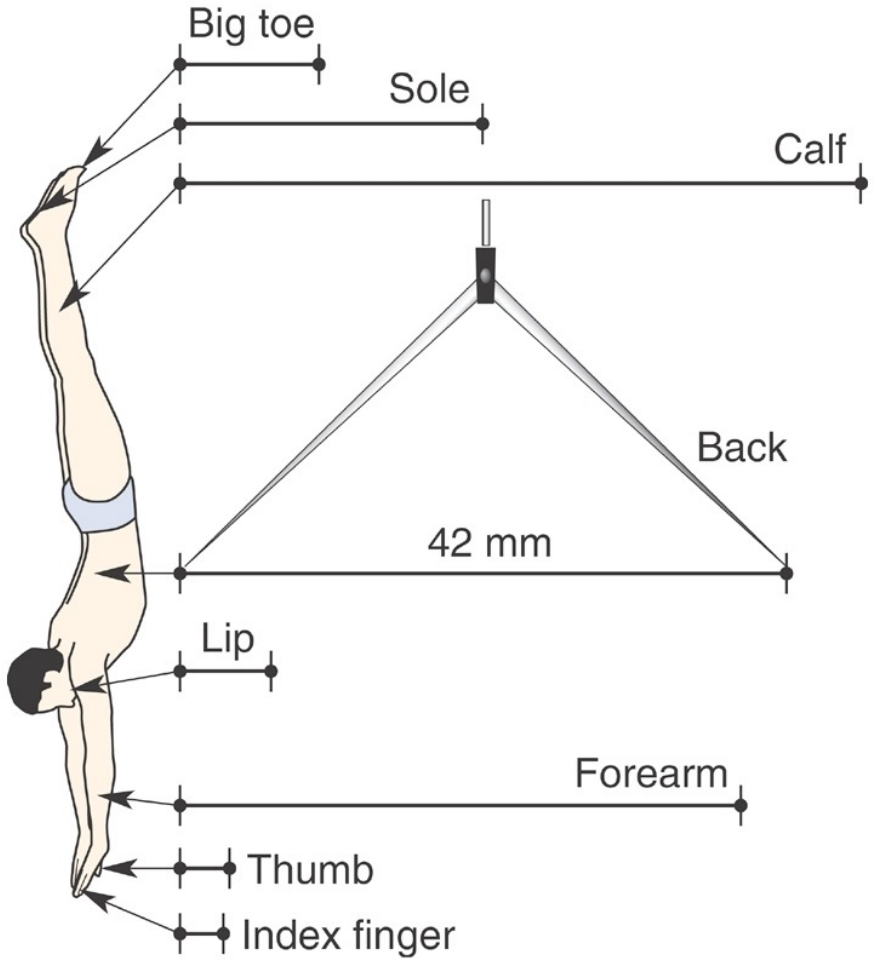


Table 10.3

Table 10.3 | The Two-Point Touch Threshold for Different Regions of the Body

Body Region	Two-Point Touch Threshold (mm)
Big toe	10
Sole of foot	22
Calf	48
Thigh	46
Back	42
Abdomen	36
Upper arm	47
Forehead	18
Palm of hand	13
Thumb	3
First finger	2

FSU!

Source: From S. Weinstein and D.R. Kenshalo, editors, *The Skin Senses,*

Somatosensory Nerves

Each somatosensory neuron has a single small **receptive field** (the area of the skin where it innervates mechanoreceptors).

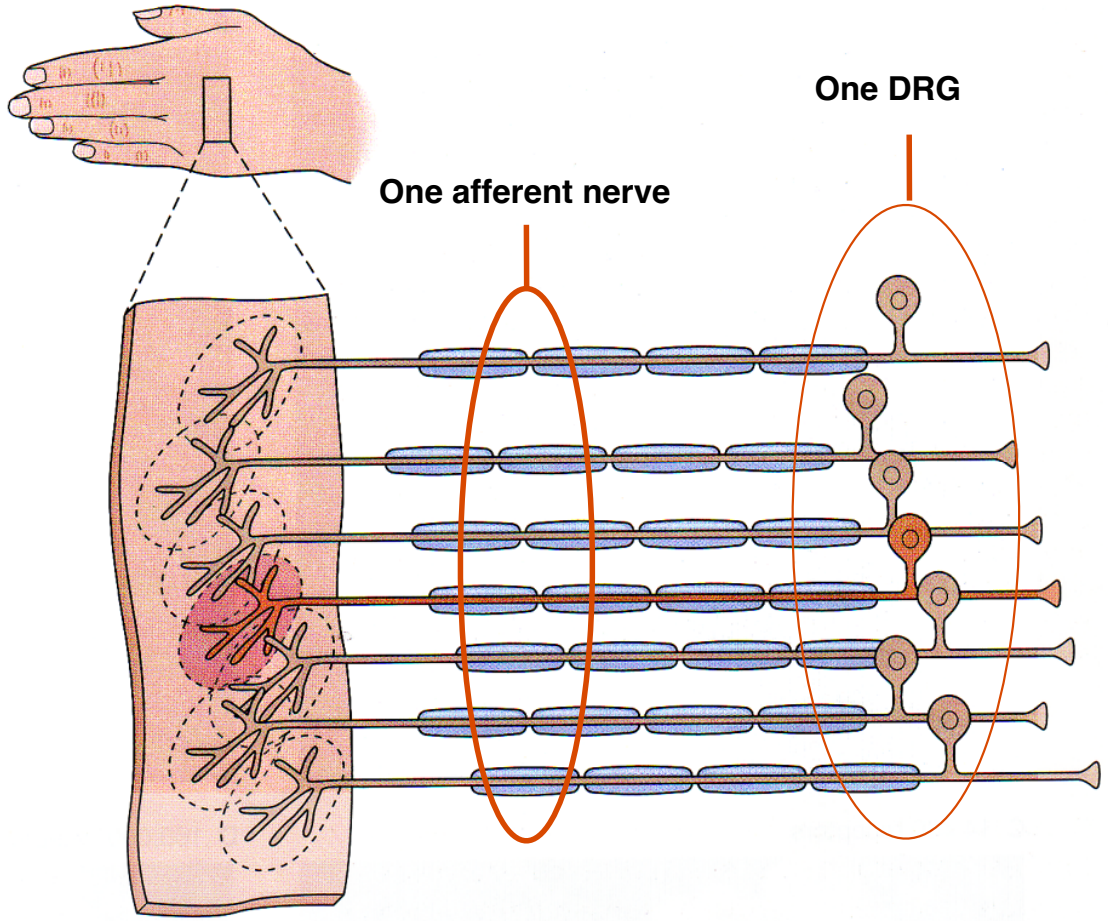
Multiple somatosensory neurons are gathered into a single **spinal nerve**. Cell bodies of the sensory neurons are gathered in **dorsal root ganglia**. Sensory afferents enter the **dorsal horn** of the spinal cord.

Each spinal nerve innervates a single segment of the body (***dermatome*** - *skin section*). Damage to a single spinal segment will affect the corresponding dermatome.

Infections of the peripheral nerves will affect specific dermatomes (e.g. herpes zoster = shingles = chicken pox)

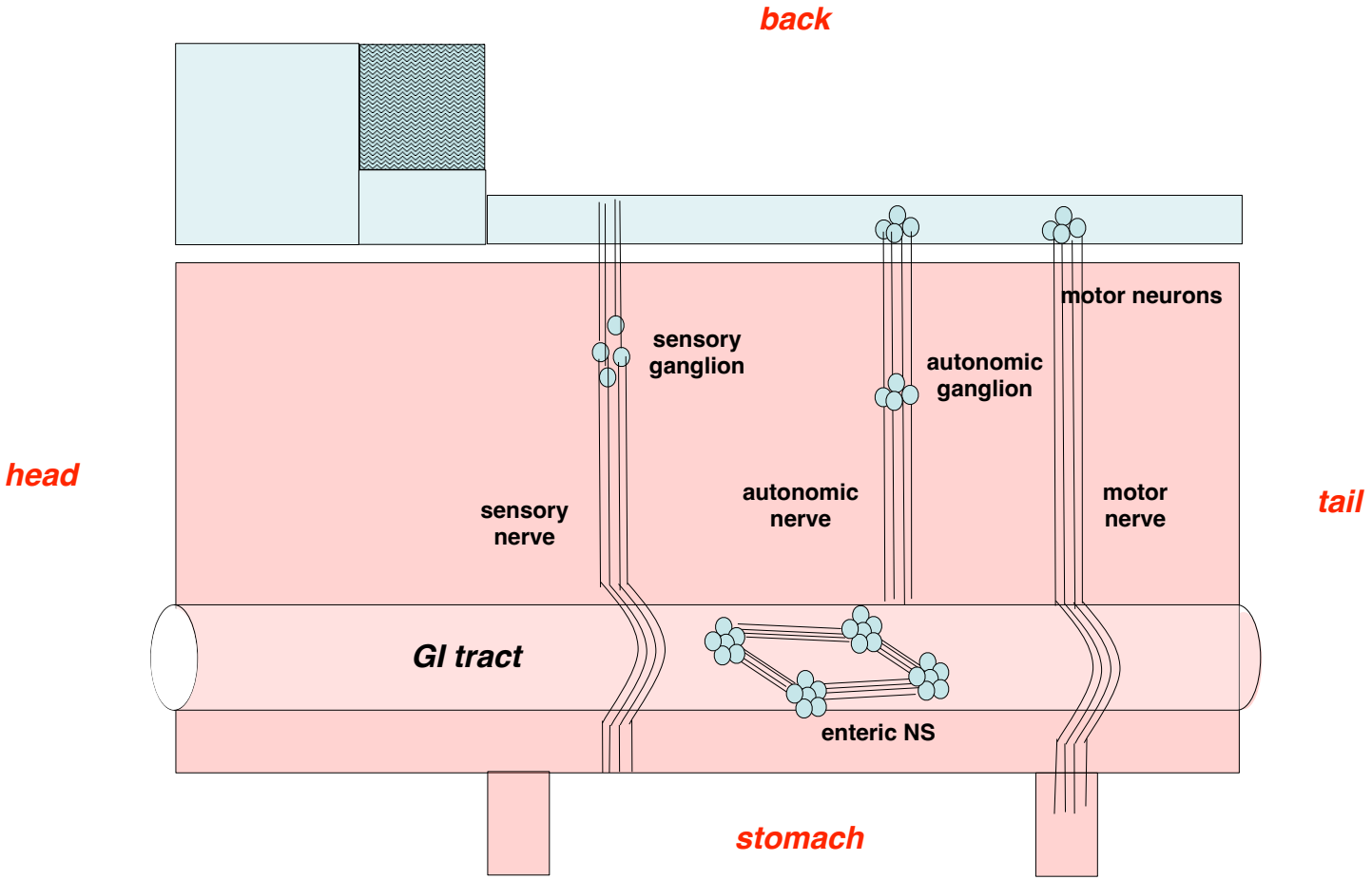
Somatosensory nerves project to **contralateral** side of the cerebral cortex.

Many afferents with overlapping receptive fields in each DRG

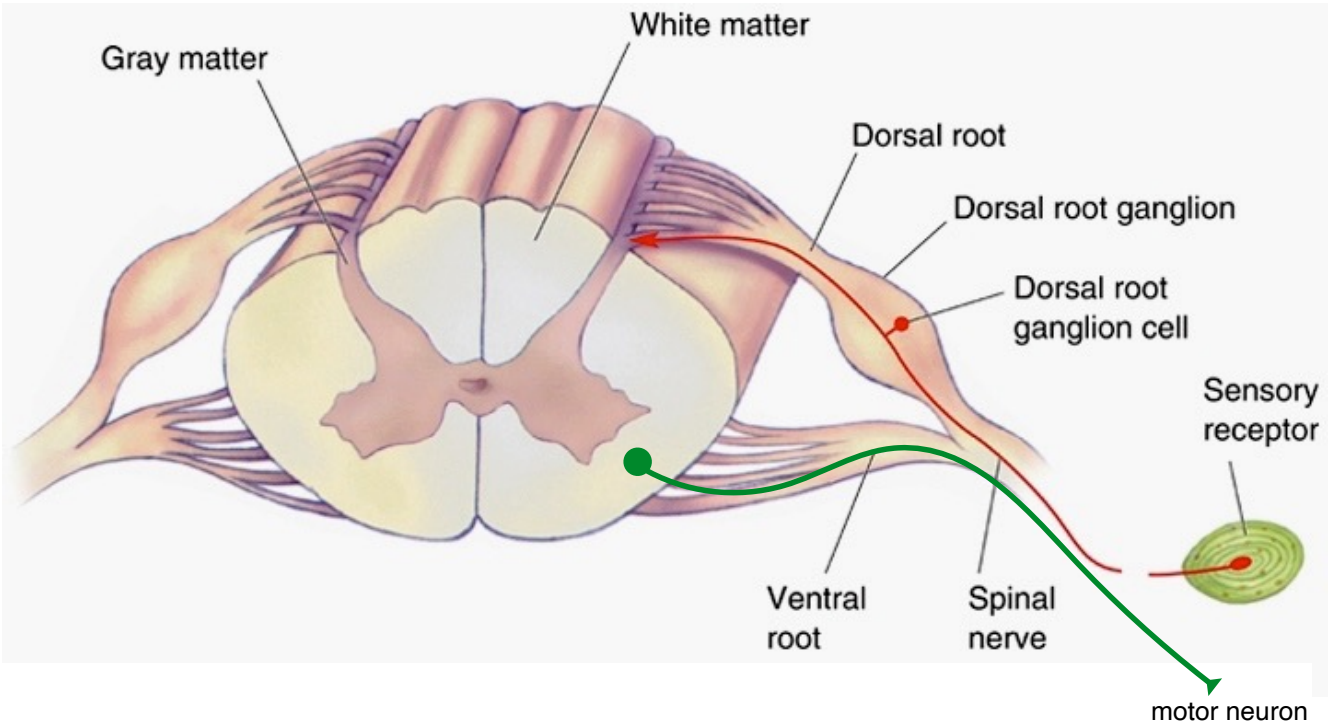


Peripheral Nervous System:

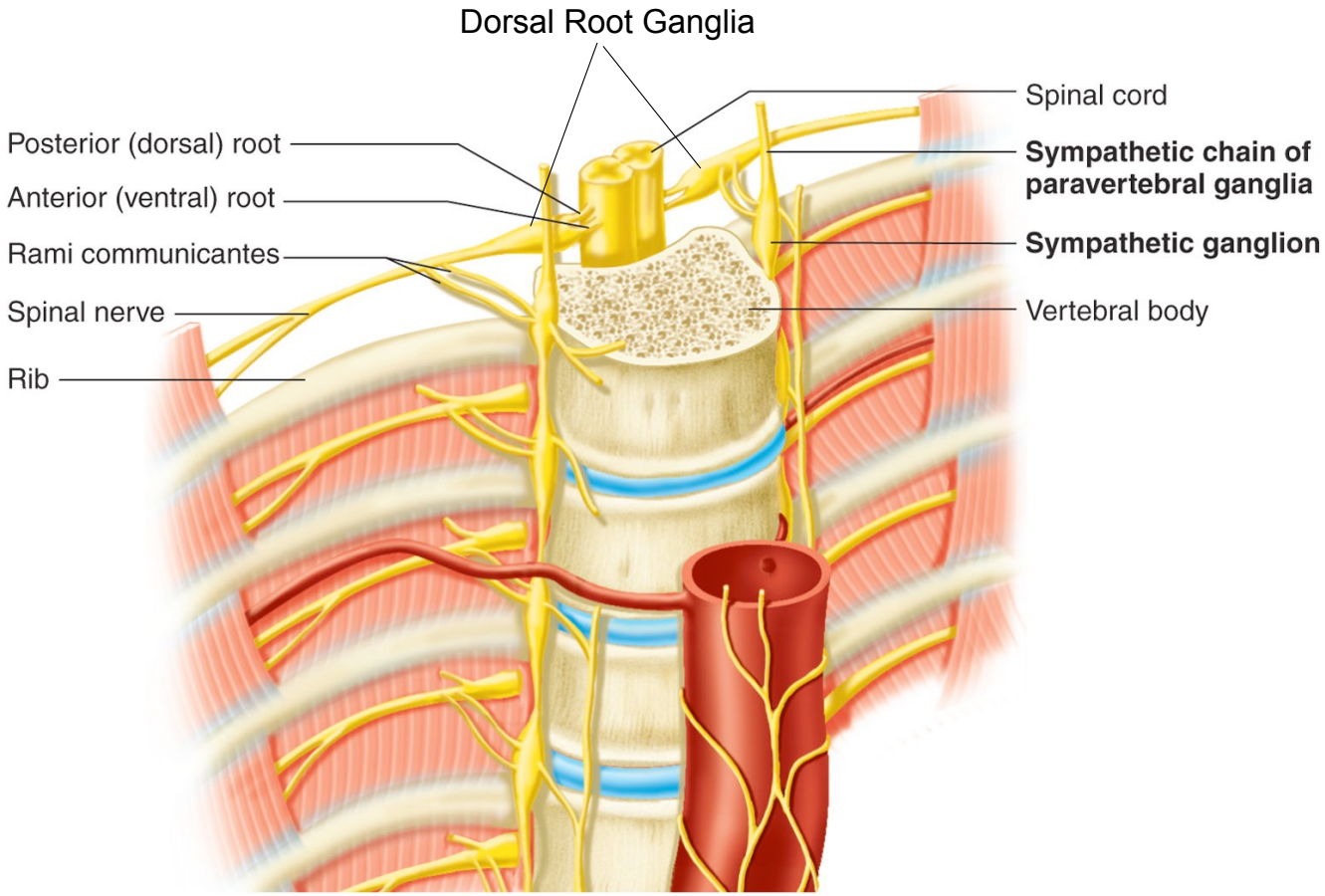
Neurons and nerve fibers outside the brain and spinal cord



Sensory afferent mechanoreceptor neuron:
cell body in DRG
projects from skin to spinal cord

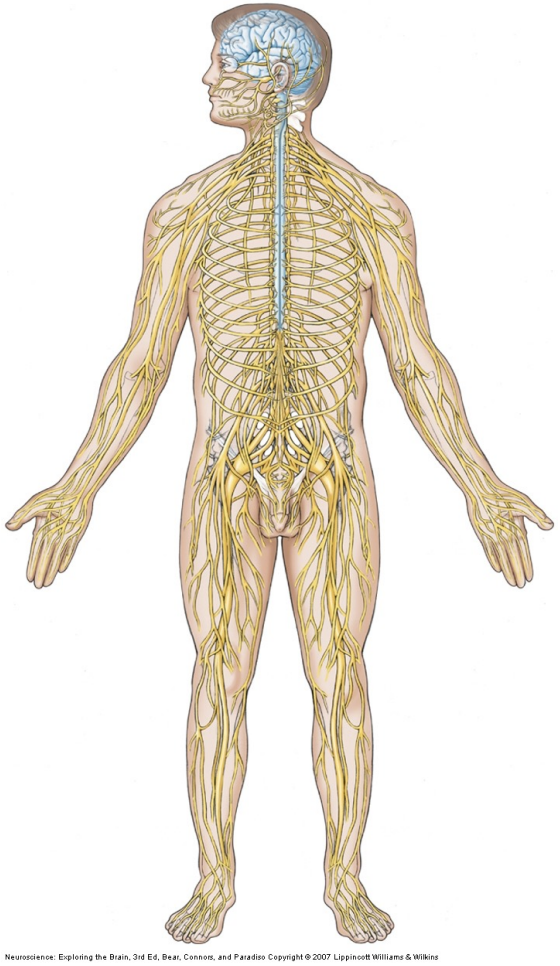


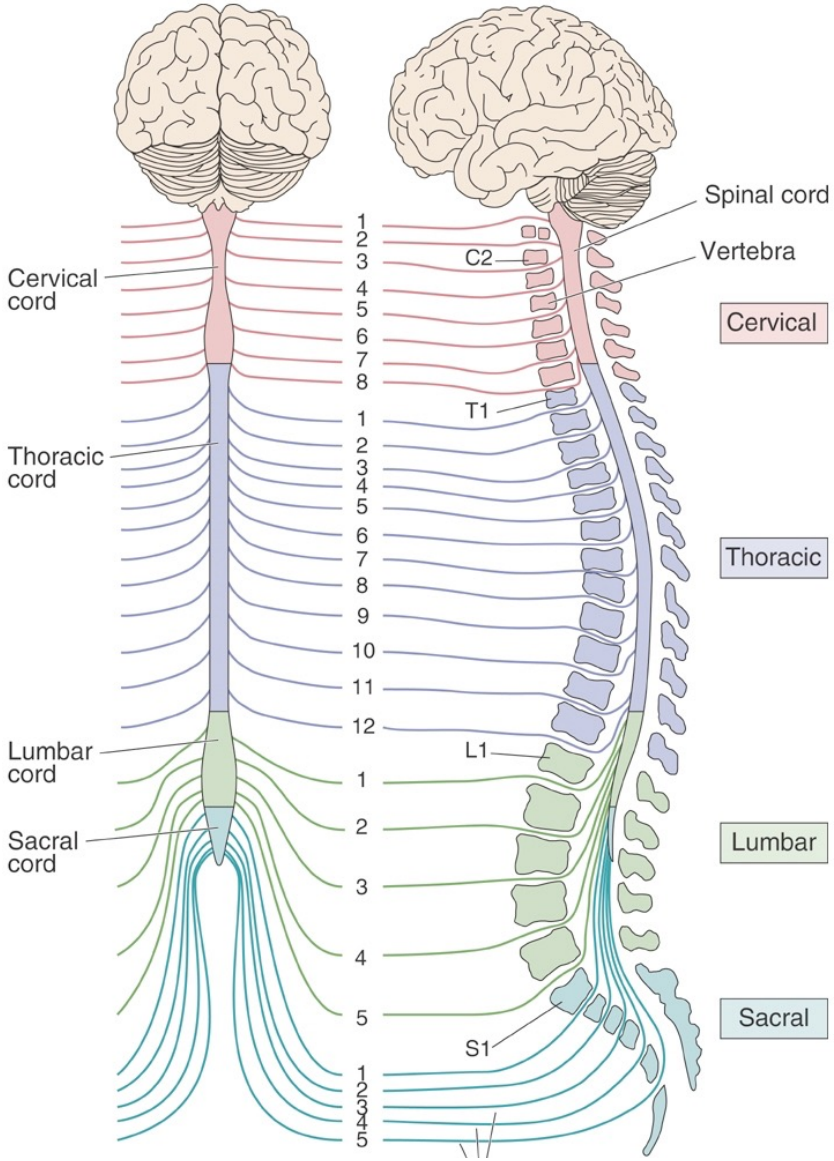
Fox Figure 9.2



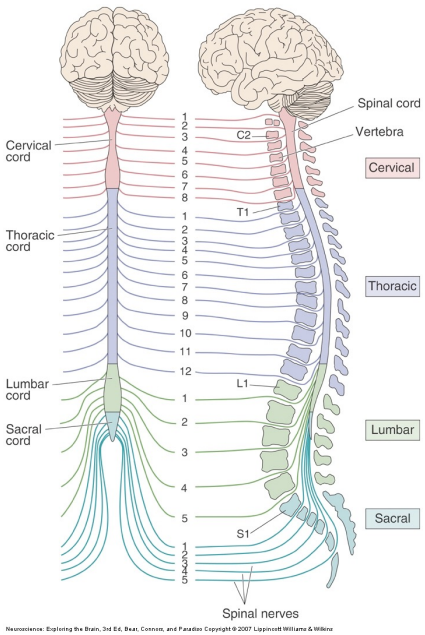
Somatic Sensory Nerves

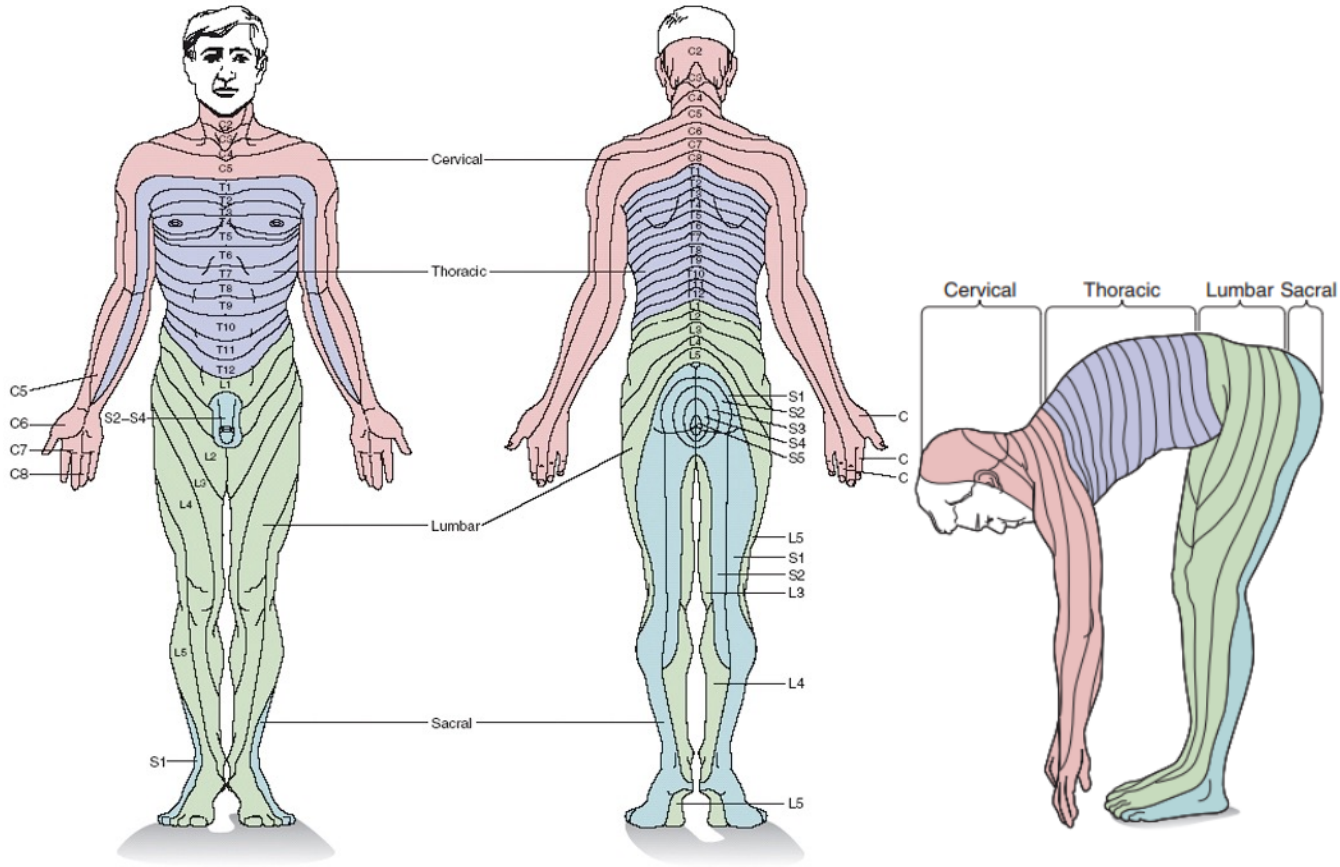
30 + cranial nerves





One DRG approx. for each vertebra: receptive fields of one DRG = dermatome





Infection by neural virus that lives in DRG cells: herpes zoster (shingles or chicken pox)

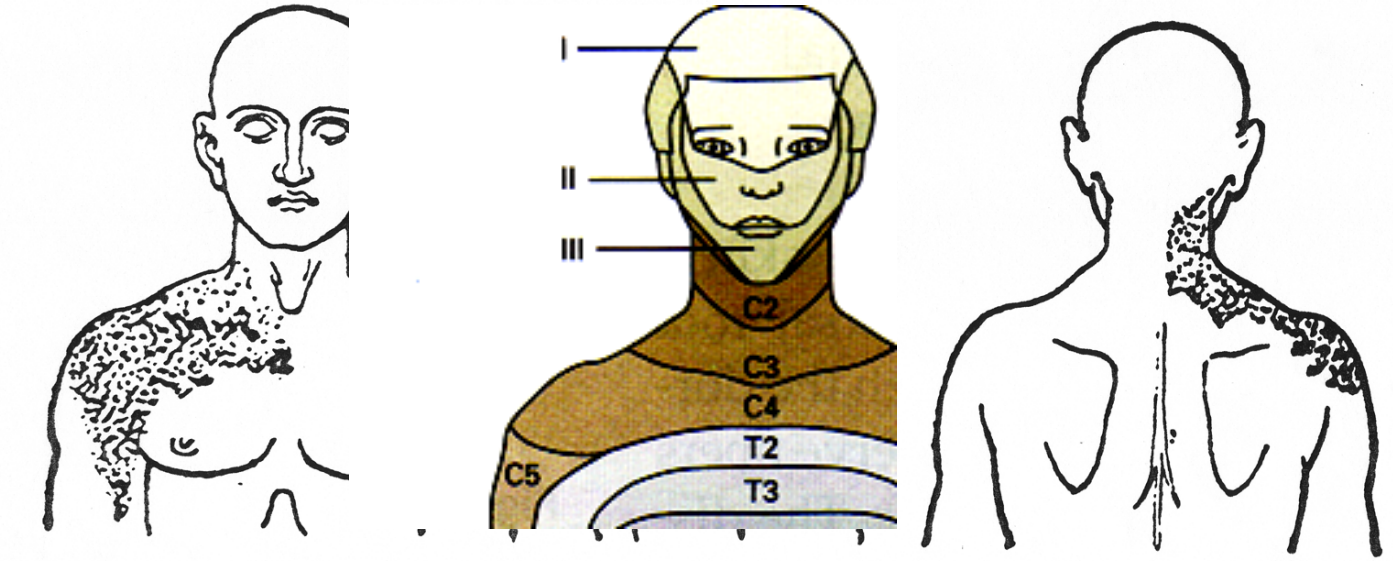
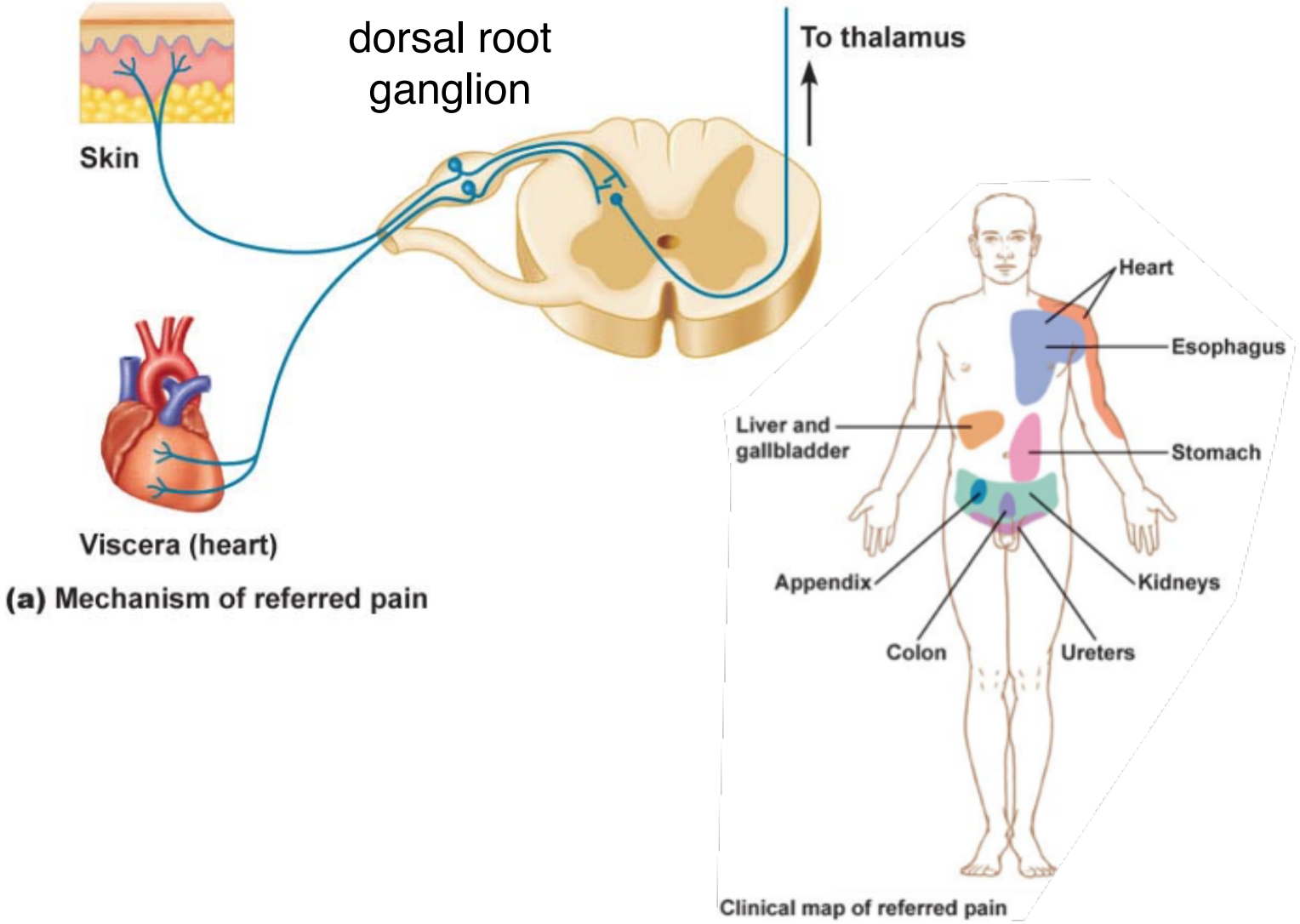


Figure 10.9. Head and Campbell (1900) compared the rashes in individual cases of herpes zoster, like the one shown above, to map the dermatomes in humans.


dorsal root ganglion
To thalamus
Skin
Viscera (heart)
(a) Mechanism of referred pain
Heart
Esophagus
Liver and gallbladder
Stomach
Appendix
Kidneys
Colon
Ureters
Clinical map of referred pain

Prosthetic hand with interface with somatosensory nerves restores sense of touch

http://www.theguardian.com/science/2014/feb/05/bionic-hand-limb-sense-touch-artificial

Somatosensory Cortex

Cortical neurons also have receptive fields that correspond to receptive fields of somatosensory nerves that provide input. Cortex uses simple receptive fields of somatosensory nerves to derive and extract more complex features.

Somatotopy: Cortical neurons are arranged in same topology as peripheral receptive fields on the skin, to make up homunculus. Areas with denser receptive fields have bigger cortical representation (more neurons dedicated to processing).

Feature extraction: Cortical somatosensory neurons have more complex receptive fields than just location. Neurons may also respond to features:

- orientation of pressures across multiple receptive fields
- direction of movement of touch across multiple receptive fields
- (input of multiple peripheral neurons converge on 1 cortical neuron)

Higher cortical levels extract even more complex features (e.g. shapes, object identification). **Stereopsis** is ability to identify the 3D shape of an object.

Ascending Somatosensory Pathways

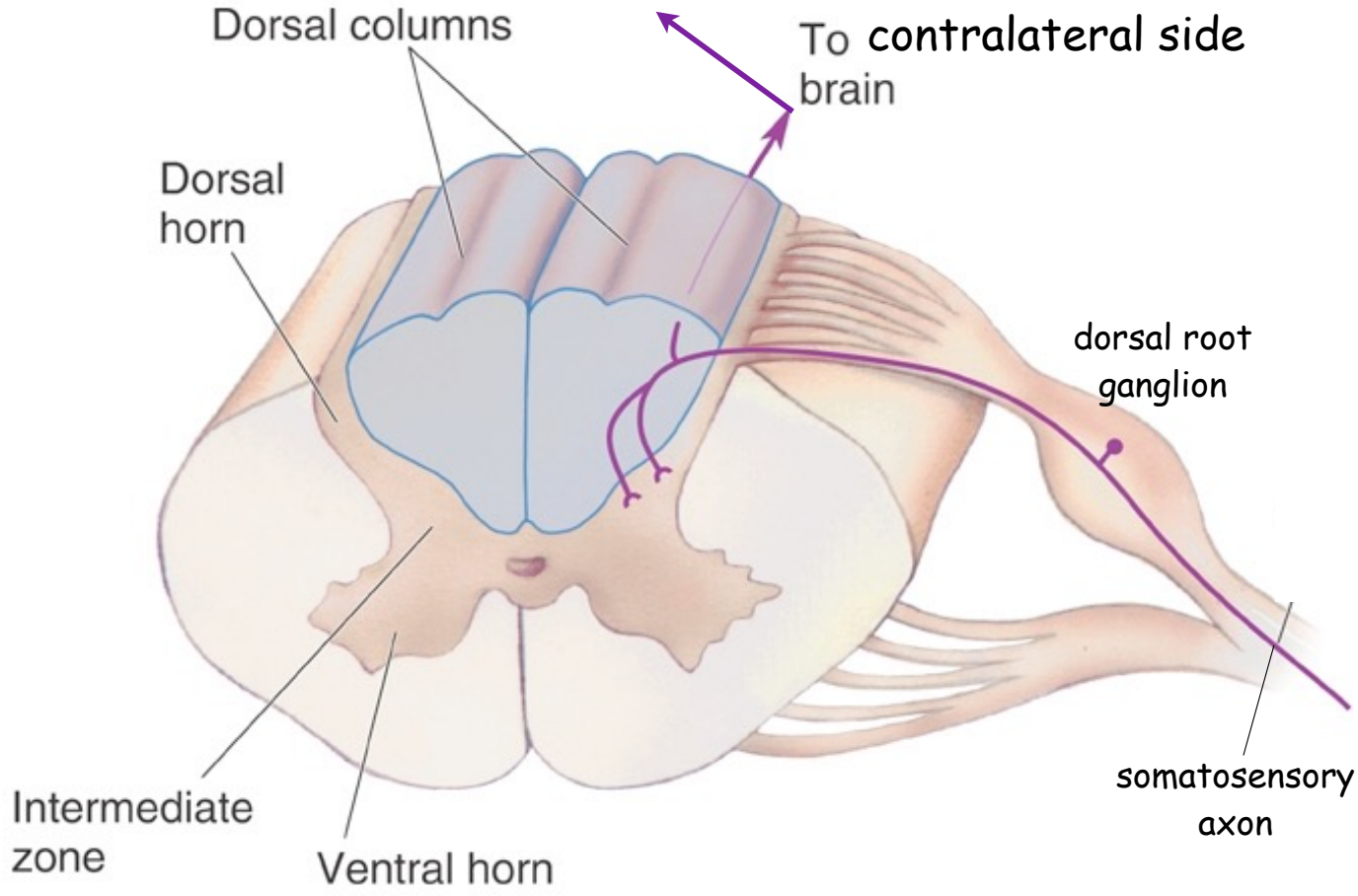
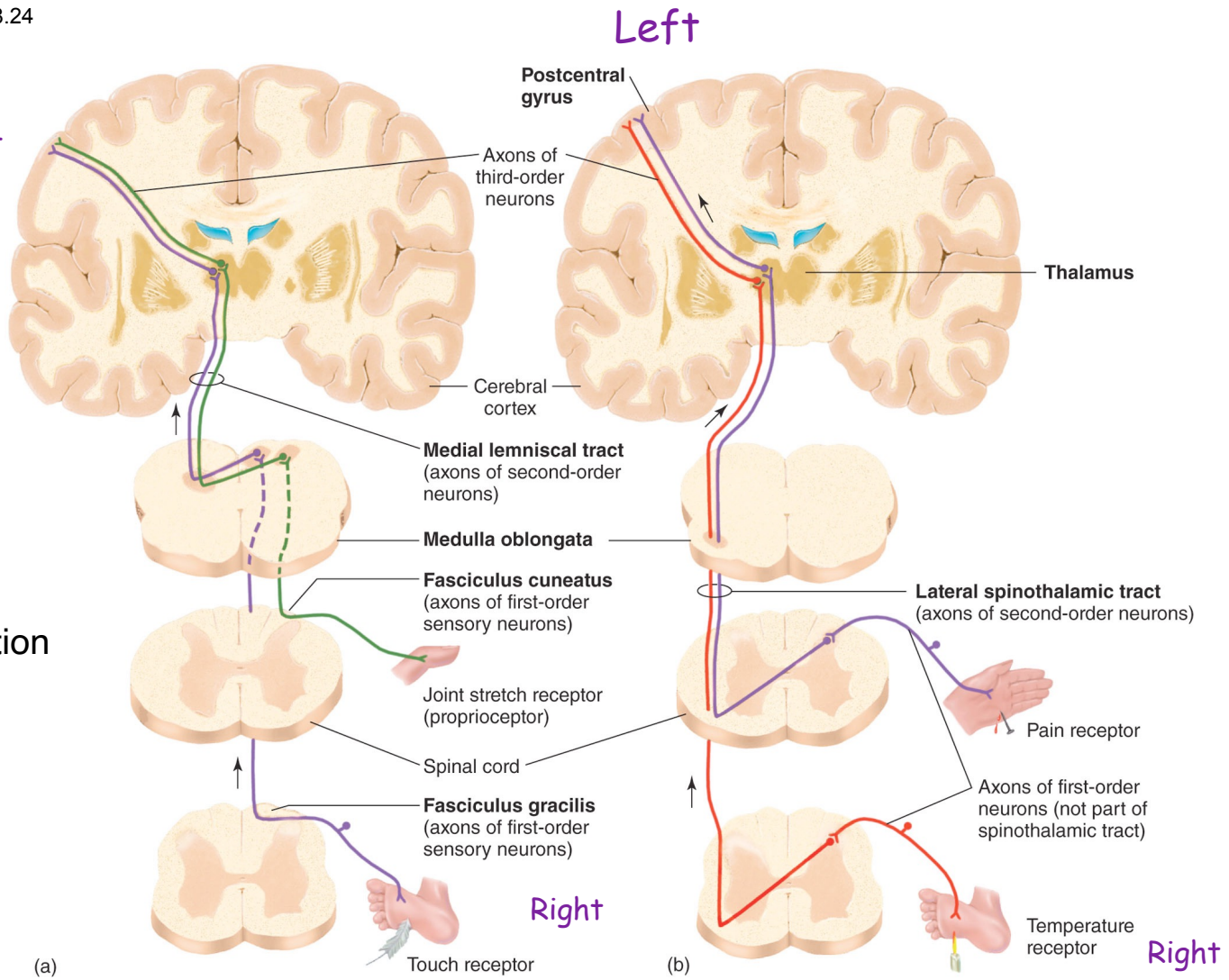


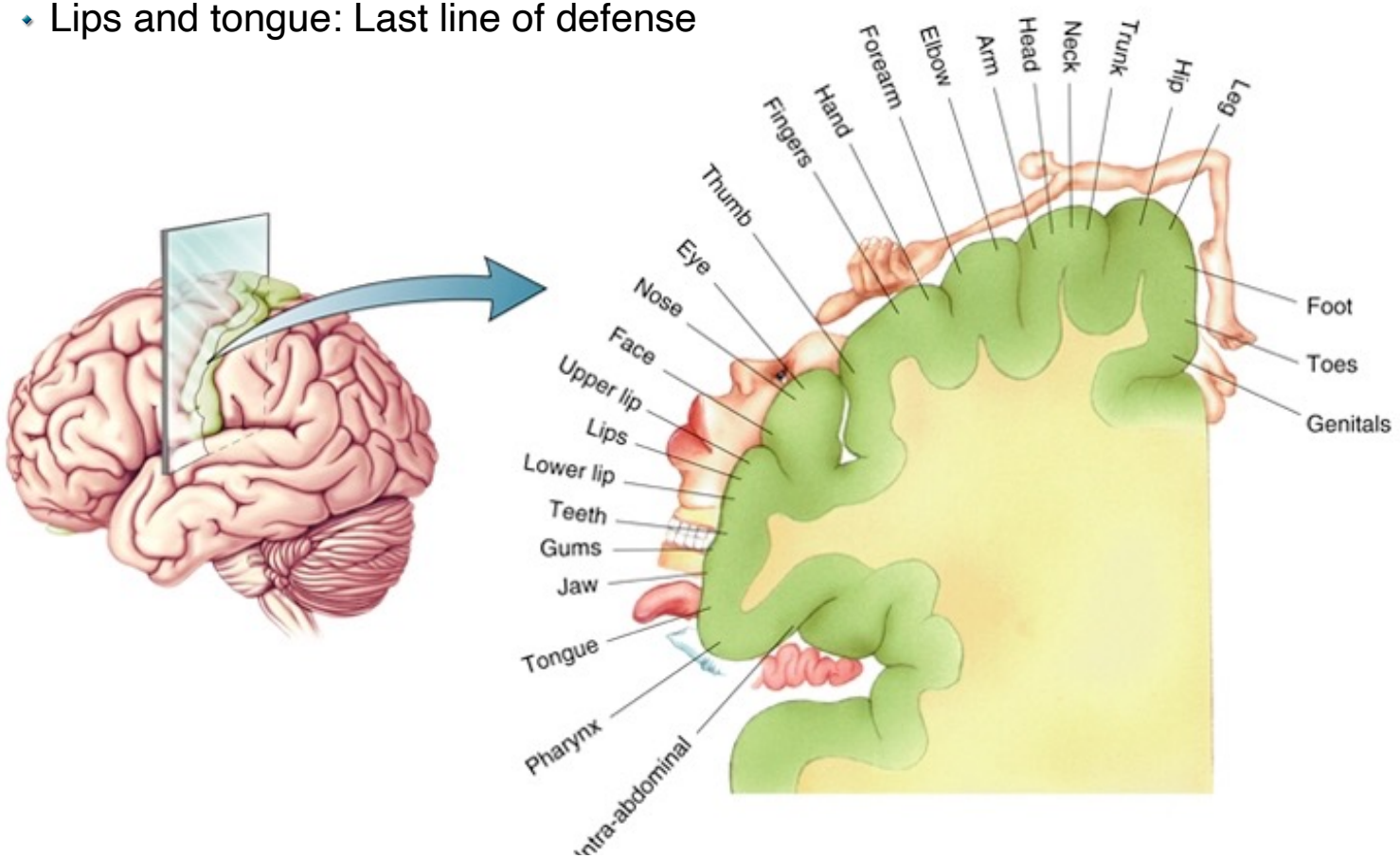
Figure 8.24



Touch, proprioception crosses over in **brainstem**

pain, temperature crosses over at entry level in **spinal cord**

- Cortical Somatotopy
  - Homunculus
  - Importance of mouth
    - Tactile sensations: Important for speech
    - Lips and tongue: Last line of defense



How to make cortical map

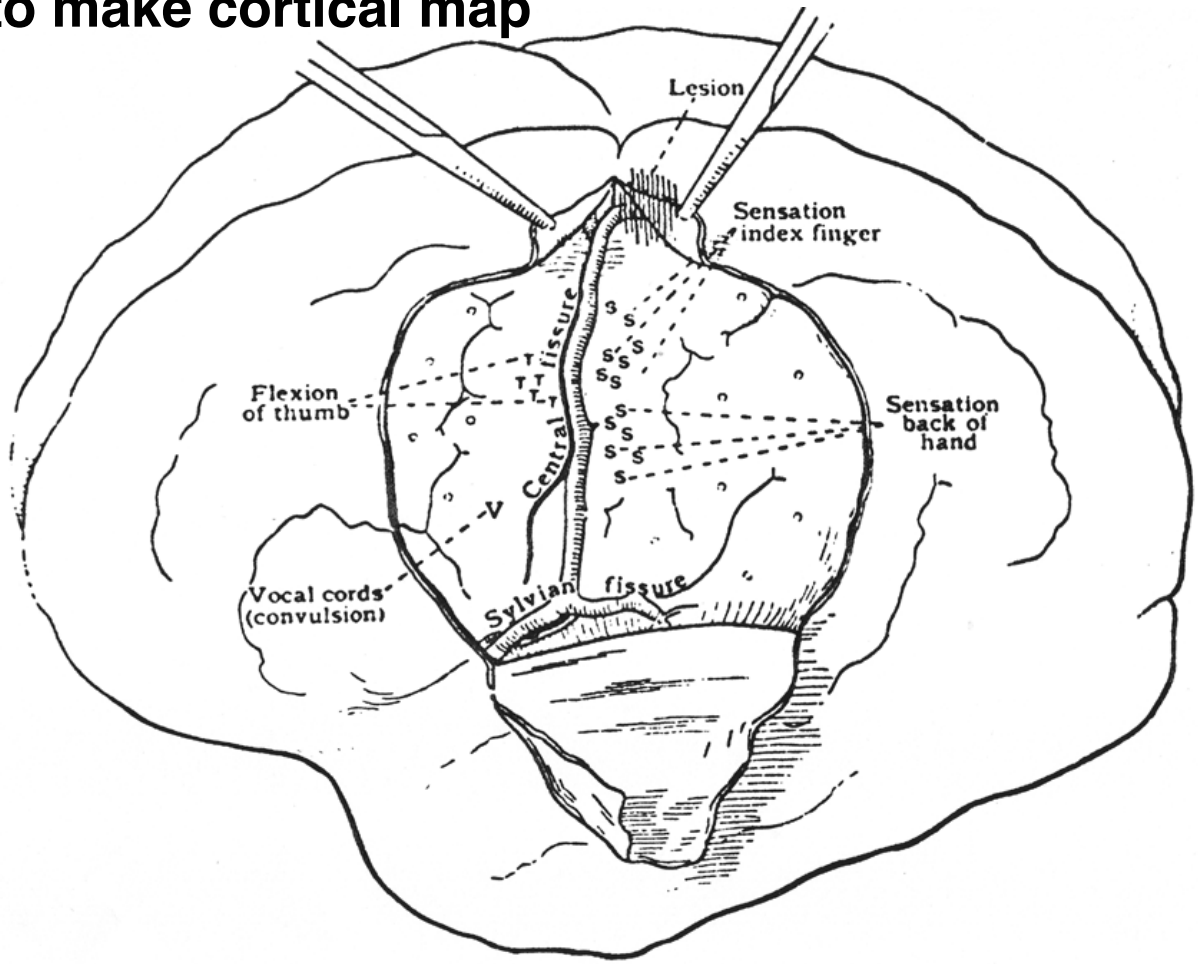


Figure 10.15. Diagram from Harvey Cushing (1909) showing distribution of sensory responses from the postcentral gyrus and motor responses from the precentral gyrus in a conscious human patient who underwent electrical stimulation of the brain.

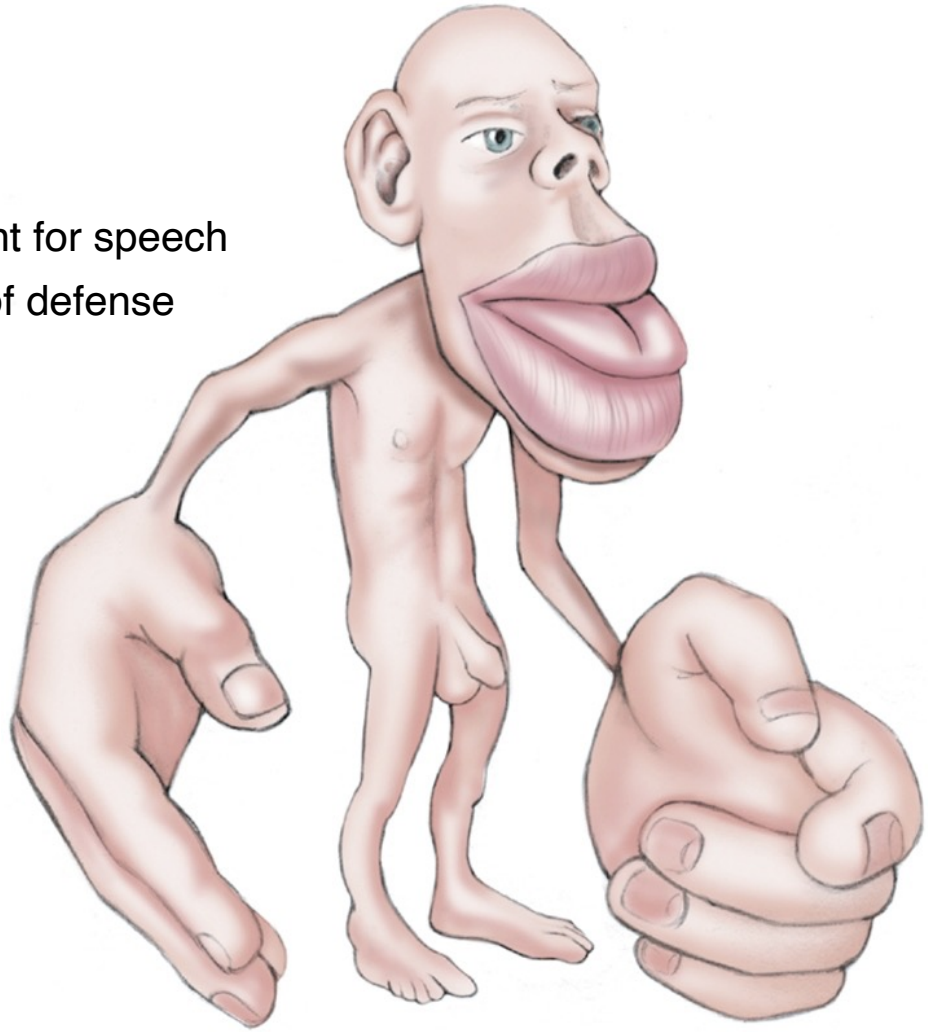
Cortical Somatotopy

Homunculus

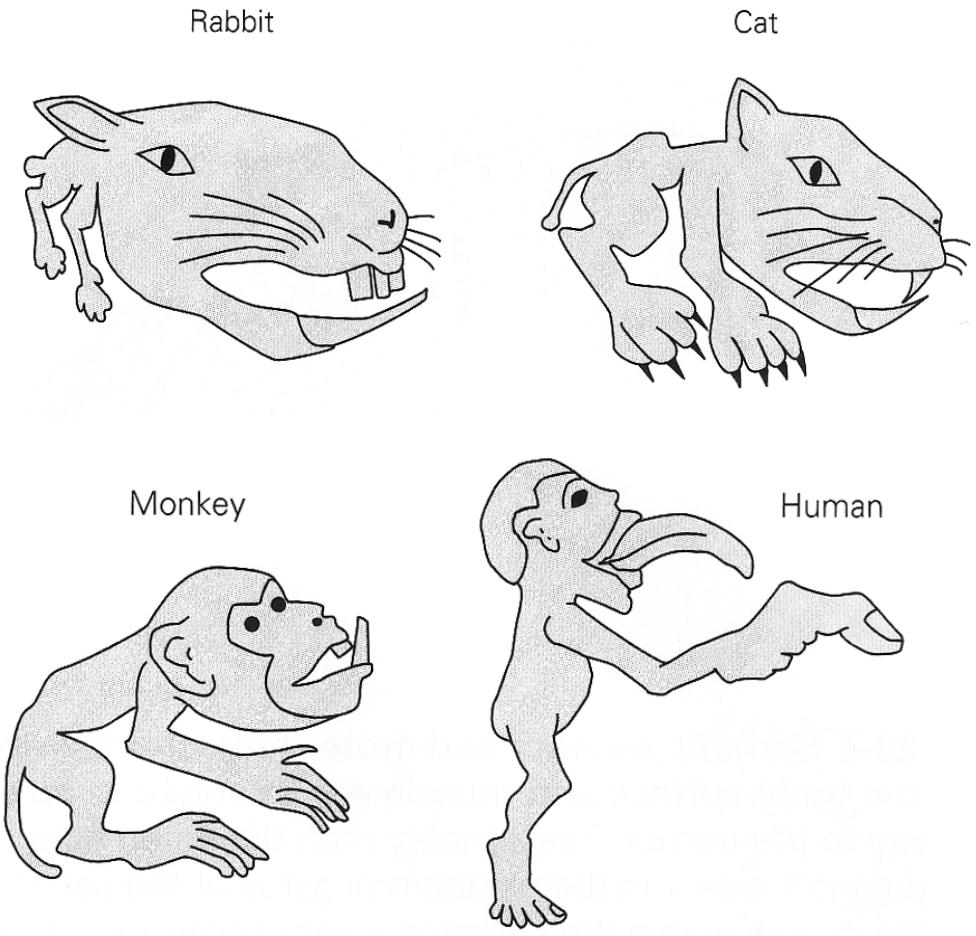
Importance of mouth

Tactile sensations: Important for speech

Lips and tongue: Last line of defense

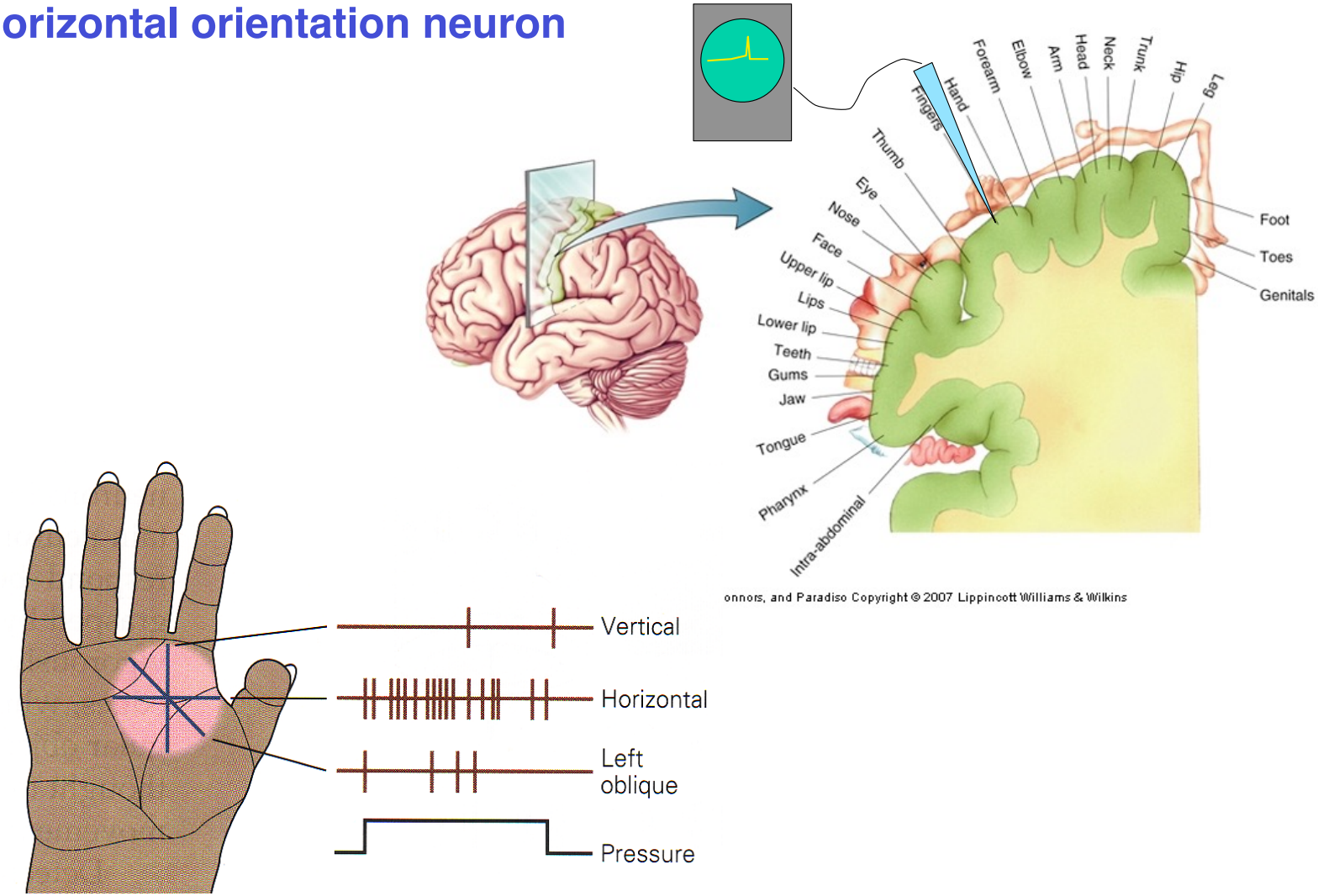


Maps differ between species



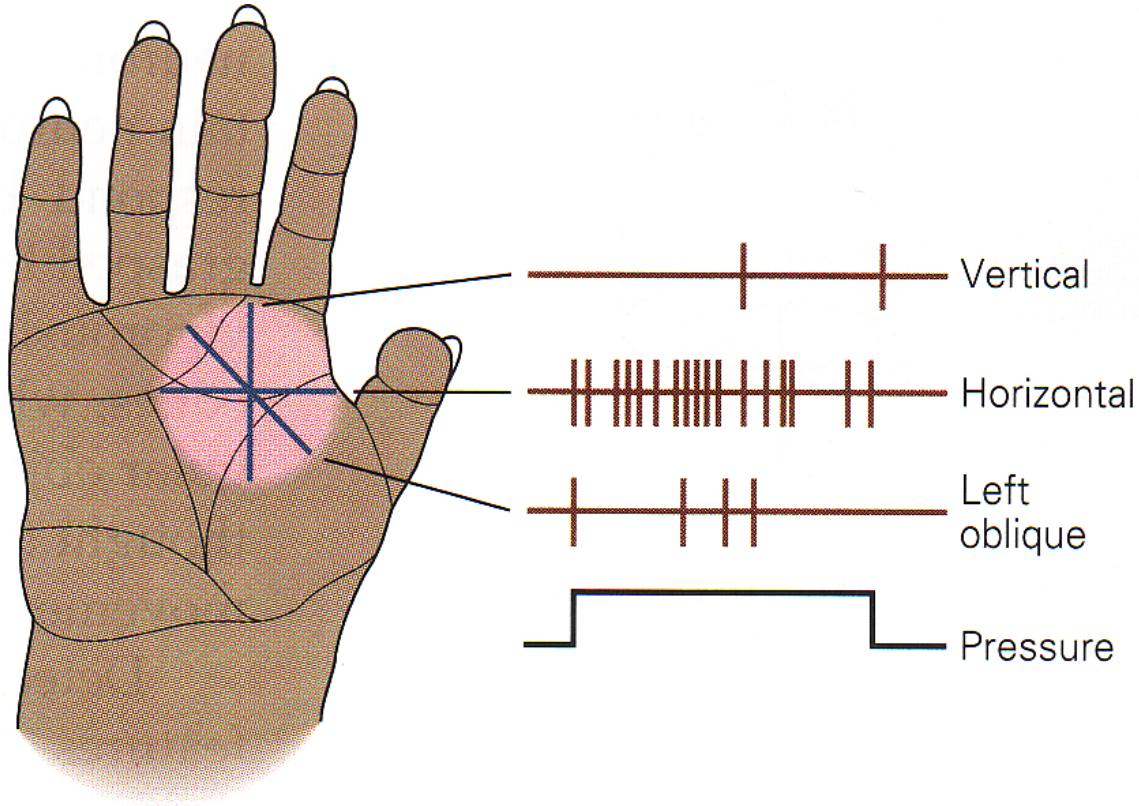
Feature extraction by cortical neurons

Horizontal orientation neuron



Feature extraction by cortical neurons

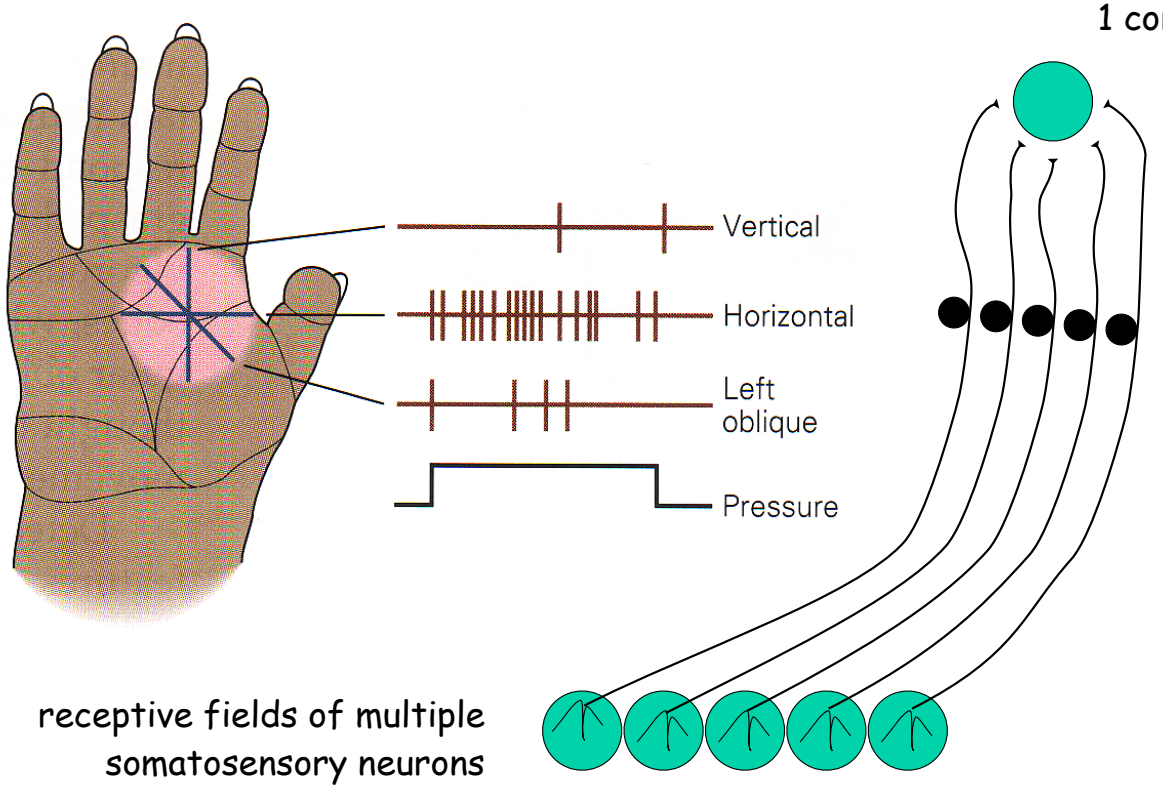
Horizontal orientation neuron



Feature extraction by cortical neurons

Horizontal orientation neuron

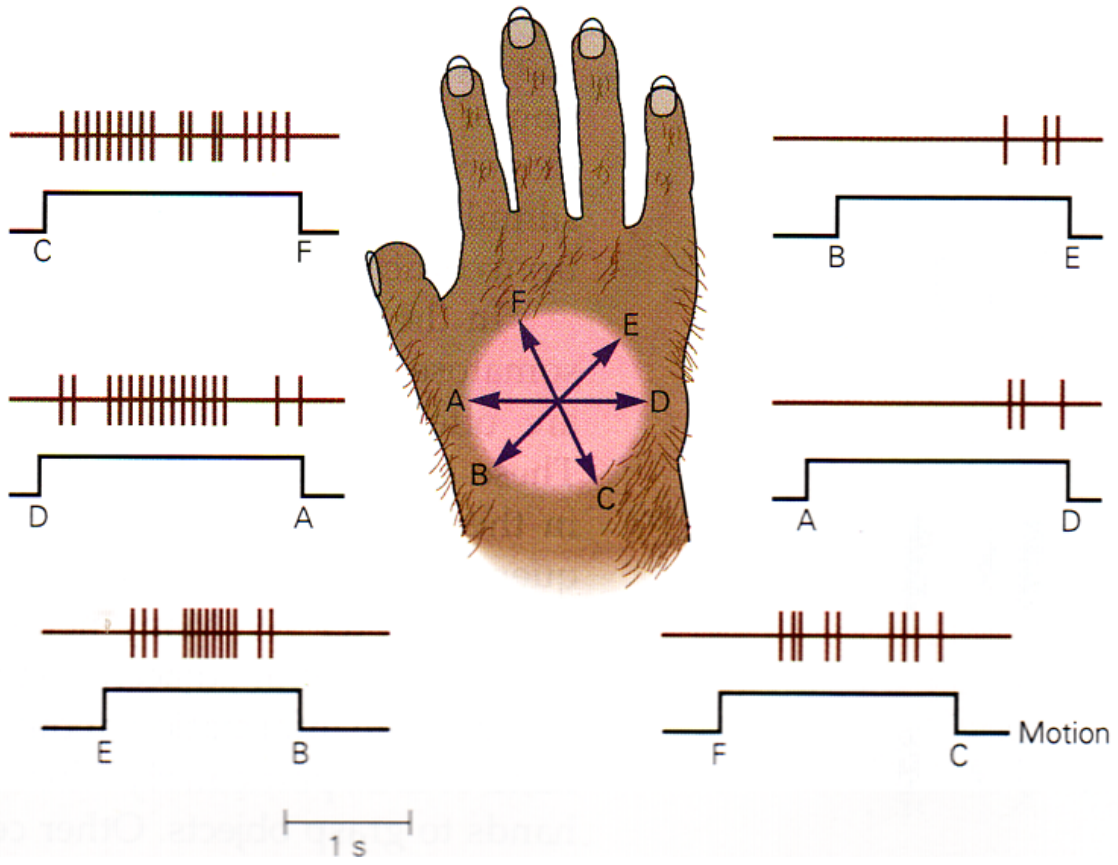
converge on
1 cortical cell



receptive fields of multiple
somatosensory neurons

Feature extraction by cortical neurons

Directional movement neuron



Stereopsis -- detecting 3D shape of an object

An excellent description of astereognosis appeared in 1898.

B.C. was 24 years old when he presented himself to Dr. Burr for treatment. When he was about 10 years old he was accidently struck on the side of the head by an axe handle with such force that he was thrown into a river, on the bank of which he had been standing. Examination of the head showed that he had a simple depressed fracture of the right parietal bone over the motor area. He remained in a state of alternating coma and delirium for about three weeks. On recovering he found himself partially paralyzed on the left side of the body and face, and completely anesthetic on the same side. The palsy and anesthesia entirely passed away in a few months, sensation returning before motion. He was supposed to have recovered completely, until, on putting his left hand into his coat pocket for the first time after his illness, he discovered that he could not tell what he had in his grasp, though he had preserved the sense of touch. (Burr, 1898, 37)