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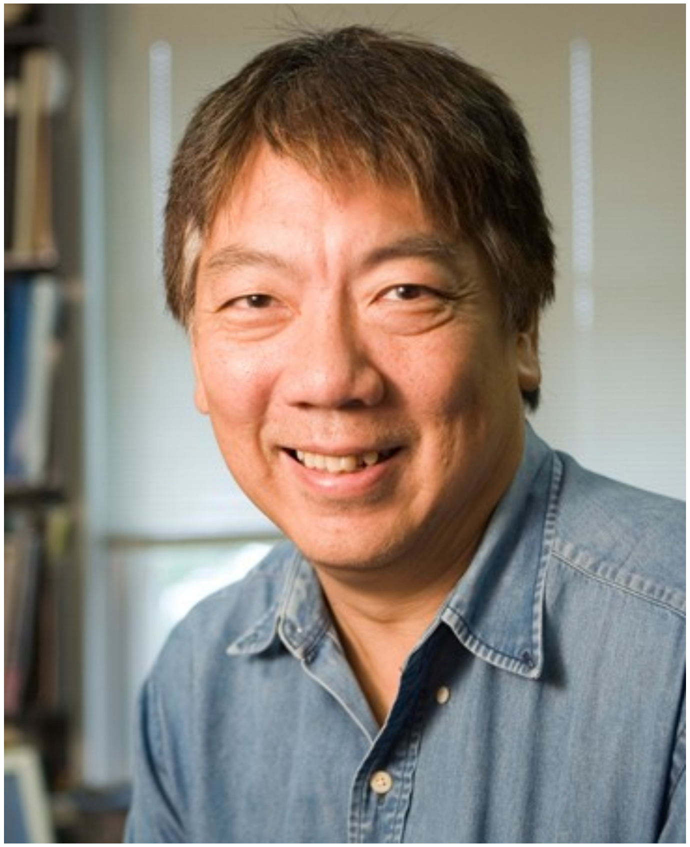
System Bioengineering II: Neurosciences

Somatosensory System

Prof. Xiaoqin Wang

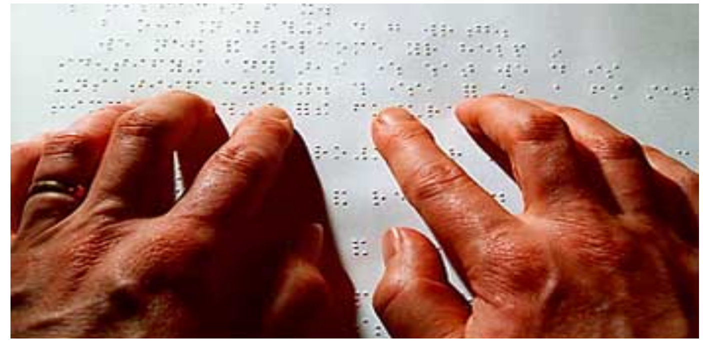
Professor Steven Hsiao (1955-2014)



Professor of Neuroscience, Biomedical Engineering and Psychological and Brain Sciences

What is the “touch” for?

Touch-2D Form and texture

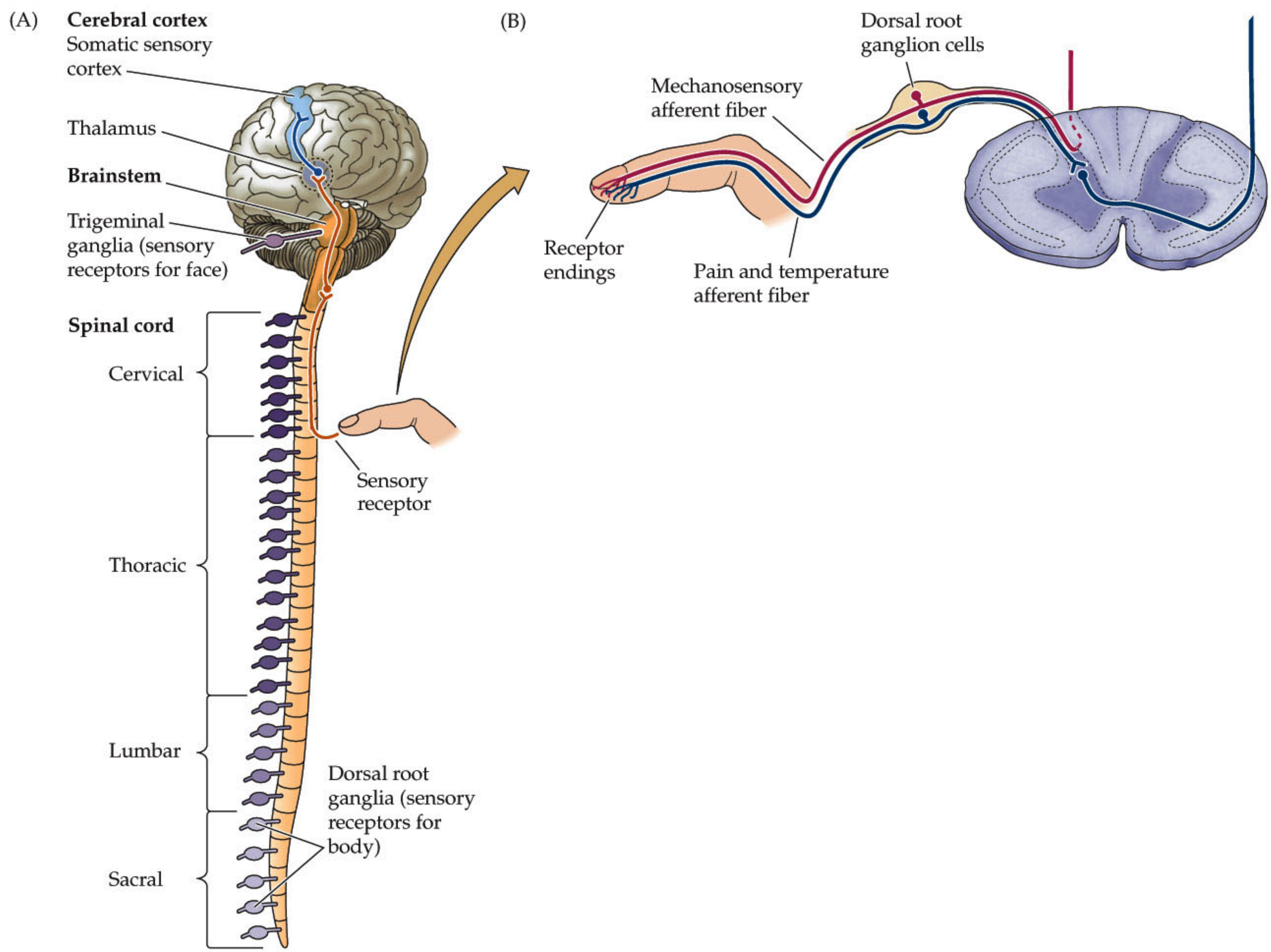


Size and shape

Tools-vibration

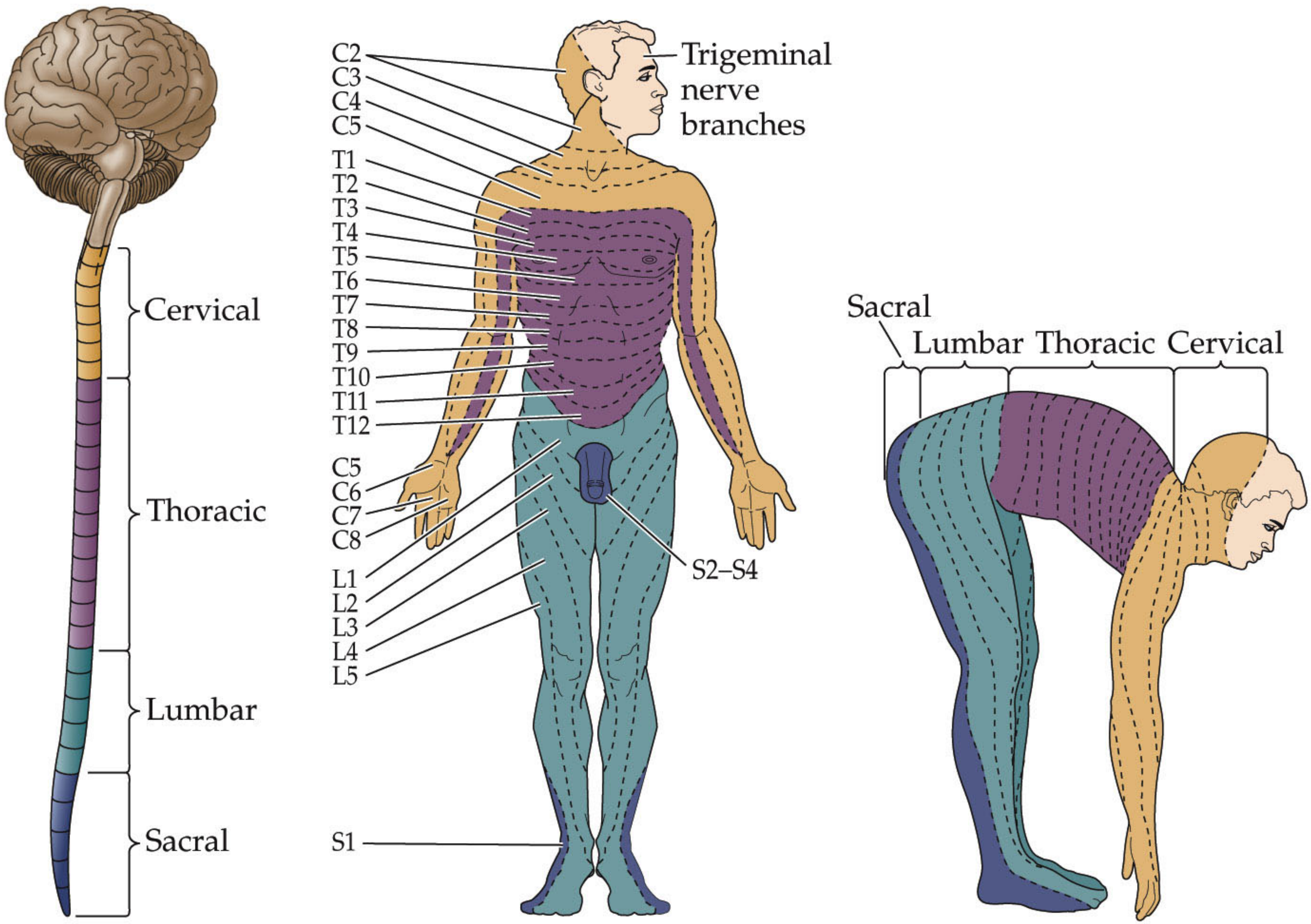
Grip and motion

Figure 9.1 Somatosensory afferents convey information from the skin surface to central circuits



NEUROSCIENCE, Fourth Edition, Figure 9.1

Box 9A Dermatomes



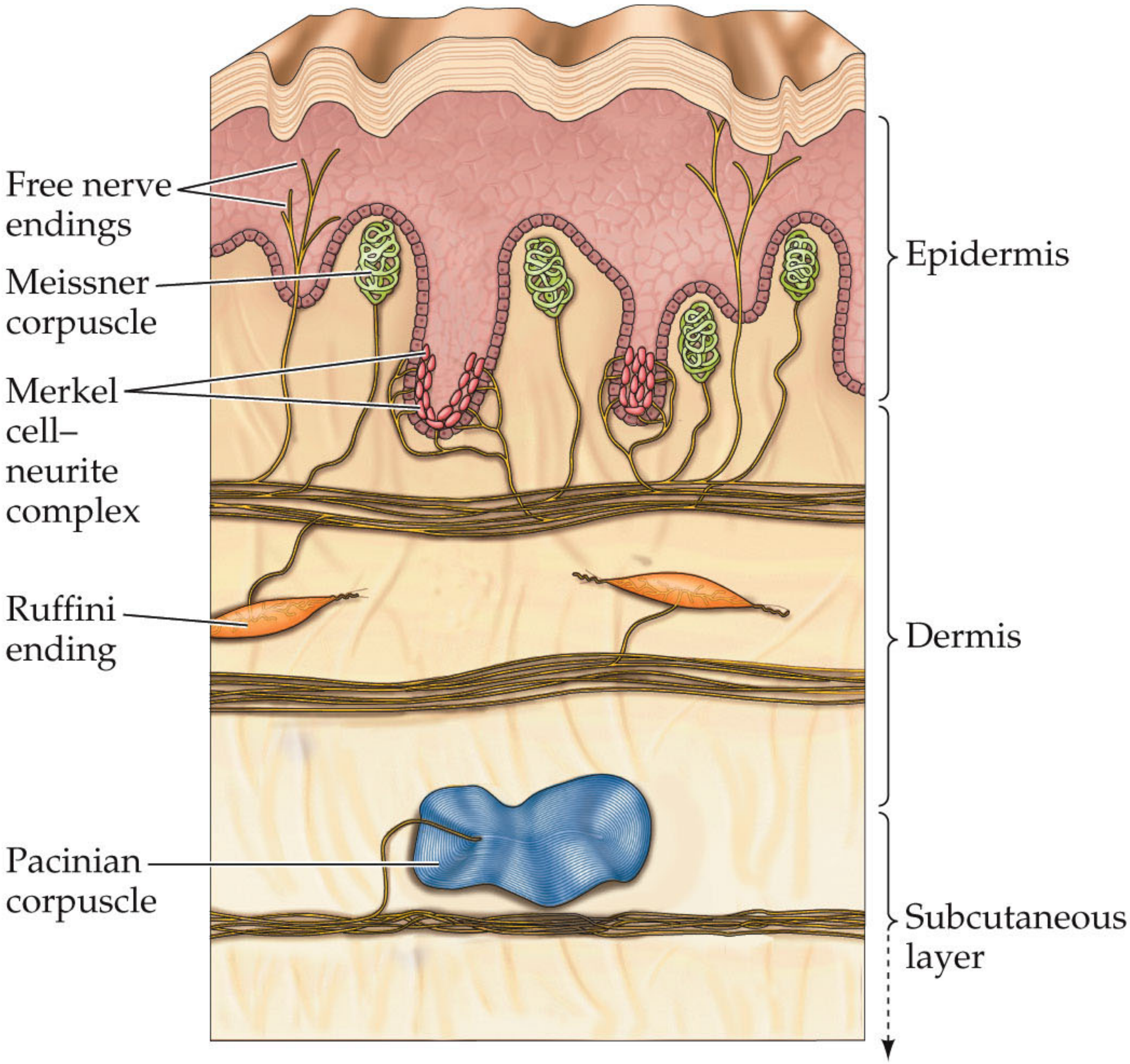
NEUROSCIENCE, Fourth Edition, Box 9A

Somatosensory Modalities

• Touch	Spatial form	(SA1)
	Texture	(SA1, PC)
	Movement	(RA)
	Flutter	(RA)
	Vibration	(PC)
• Pain	Pricking Pain	(A –delta)
	Burning Pain	(C fiber)
• Temperature	Cold	(A -delta)
	Warm	(C fiber)
• Itch		(C fiber)

Tactile Receptors

Figure 9.5 The skin harbors a variety of morphologically distinct mechanoreceptors



NEUROSCIENCE, Fourth Edition, Figure 9.5

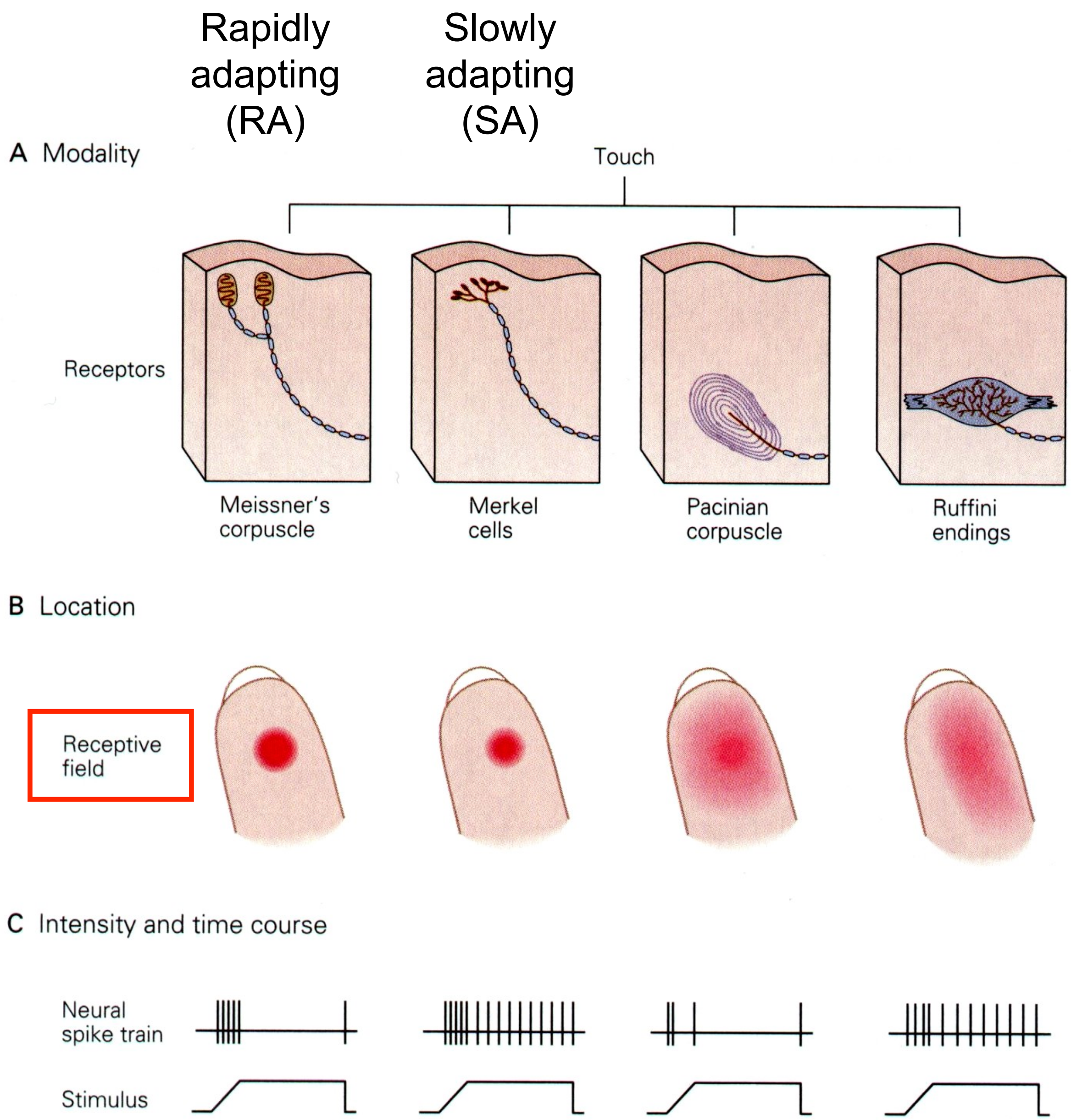

Rapidly adapting (RA)
Slowly adapting (SA)
A Modality
Touch
Receptors
Meissner's corpuscle
Merkel cells
Pacinian corpuscle
Ruffini endings
B Location
Receptive field
C Intensity and time course
Neural spike train
Stimulus

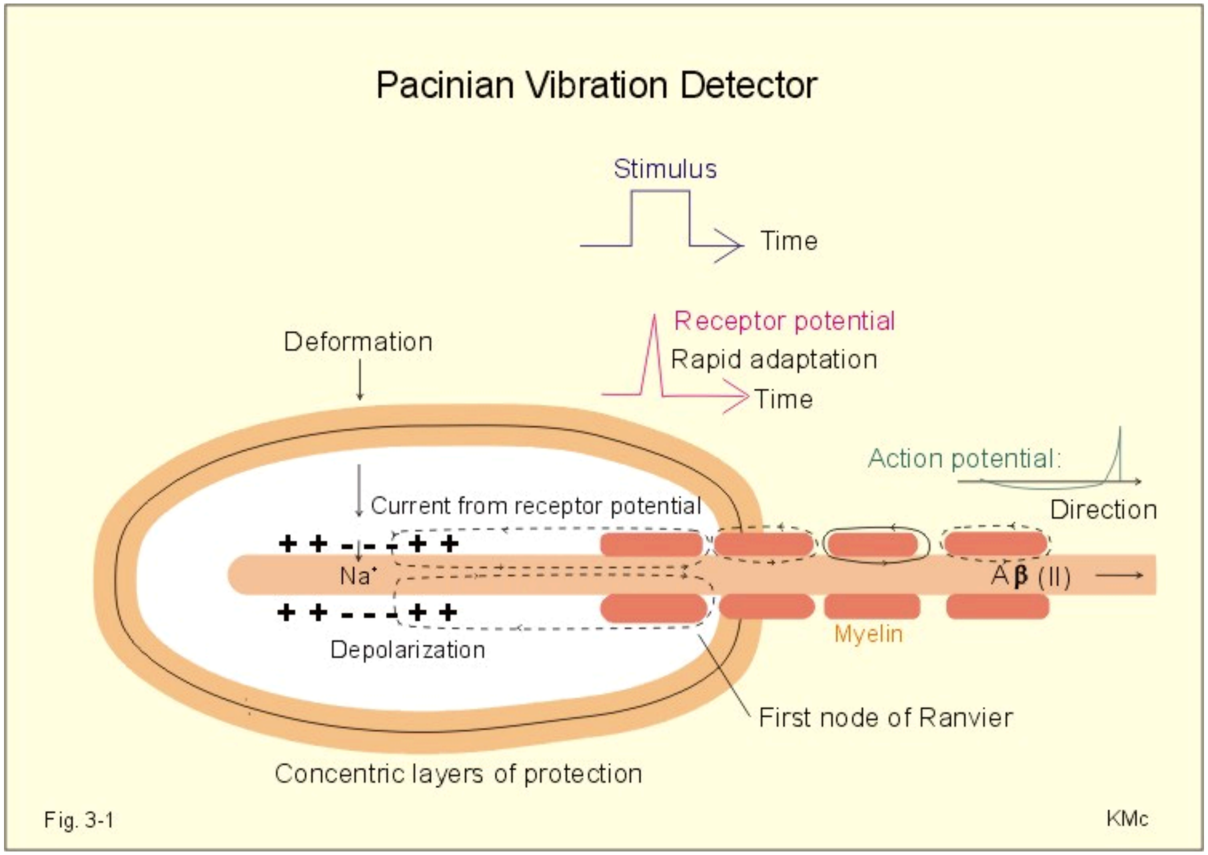
TABLE 9.2 Afferent Systems and Their Properties

	Small receptor field		Large receptor field	
	Merkel	Meissner	Pacinian	Ruffini
Location	Tip of epidermal sweat ridges	Dermal papillae (close to skin surface)	Dermis and deeper tissues	Dermis
Axon diameter	7–11 μm	6–12 μm	6–12 μm	6–12 μm
Conduction velocity	40–65 m/s	35–70 m/s	35–70 m/s	35–70 m/s
Sensory function	Form and texture perception	Motion detection; grip control	Perception of distant events through transmitted vibrations; tool use	Tangential force; hand shape; motion direction
Effective stimuli	Edges, points, corners, curvature	Skin motion	Vibration	Skin stretch
Receptive field area[a]	9 mm^2	22 mm^2	Entire finger or hand	60 mm^2
Innervation density (finger pad)	100/cm^2	150/cm^2	20/cm^2	10/cm^2
Spatial acuity	0.5 mm	3 mm	10+ mm	7+ mm
Response to sustained indentation	Sustained (slow adaptation) SA1	None (rapid adaptation) RA	None (rapid adaptation) PC	Sustained (slow adaptation) SA2
Frequency range	0–100 Hz	1–300 Hz	5–1000 Hz	0–? Hz
Peak sensitivity	5 Hz	50 Hz	200 Hz	0.5 Hz
Threshold for rapid indentation or vibration:				
Best	8 μm	2 μm	0.01 μm	40 μm
Mean	30 μm	6 μm	0.08 μm	300 μm

[a]Receptive field areas as measured with rapid 0.5-mm indentation.
(After K. O. Johnson, 2002.)

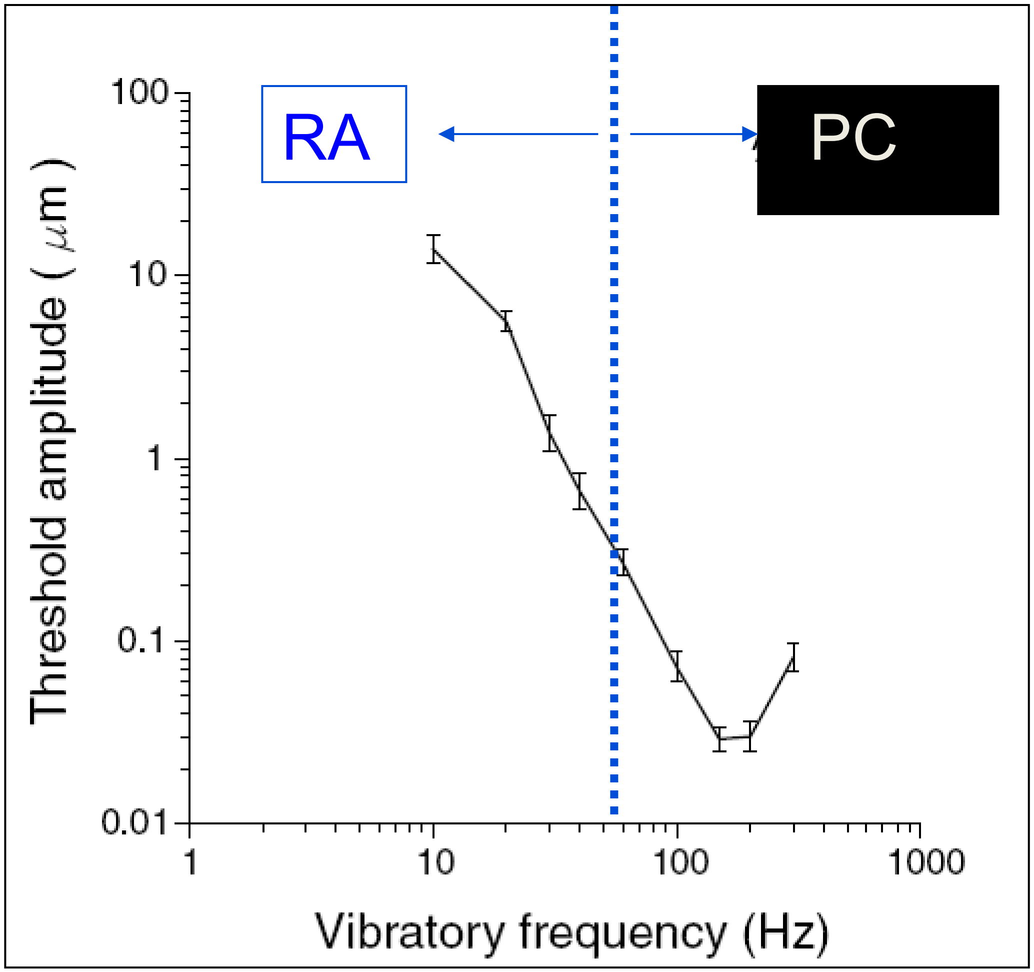
NEUROSCIENCE, Fourth Edition, Table 9.2

Pacinian Response



The tip of the axon at the center of a Pacinian is very sensitive to quick, short movements of the skin. That mechanical stimulus opens cation channels at the tips. The depolarization travels passively to the first node of Ranvier, where a large number voltage-gated Na+ channels open and initiate an action potential.

Flutter /vibration



Somatic Sensory Afferents

Receptor endings on peripheral afferents

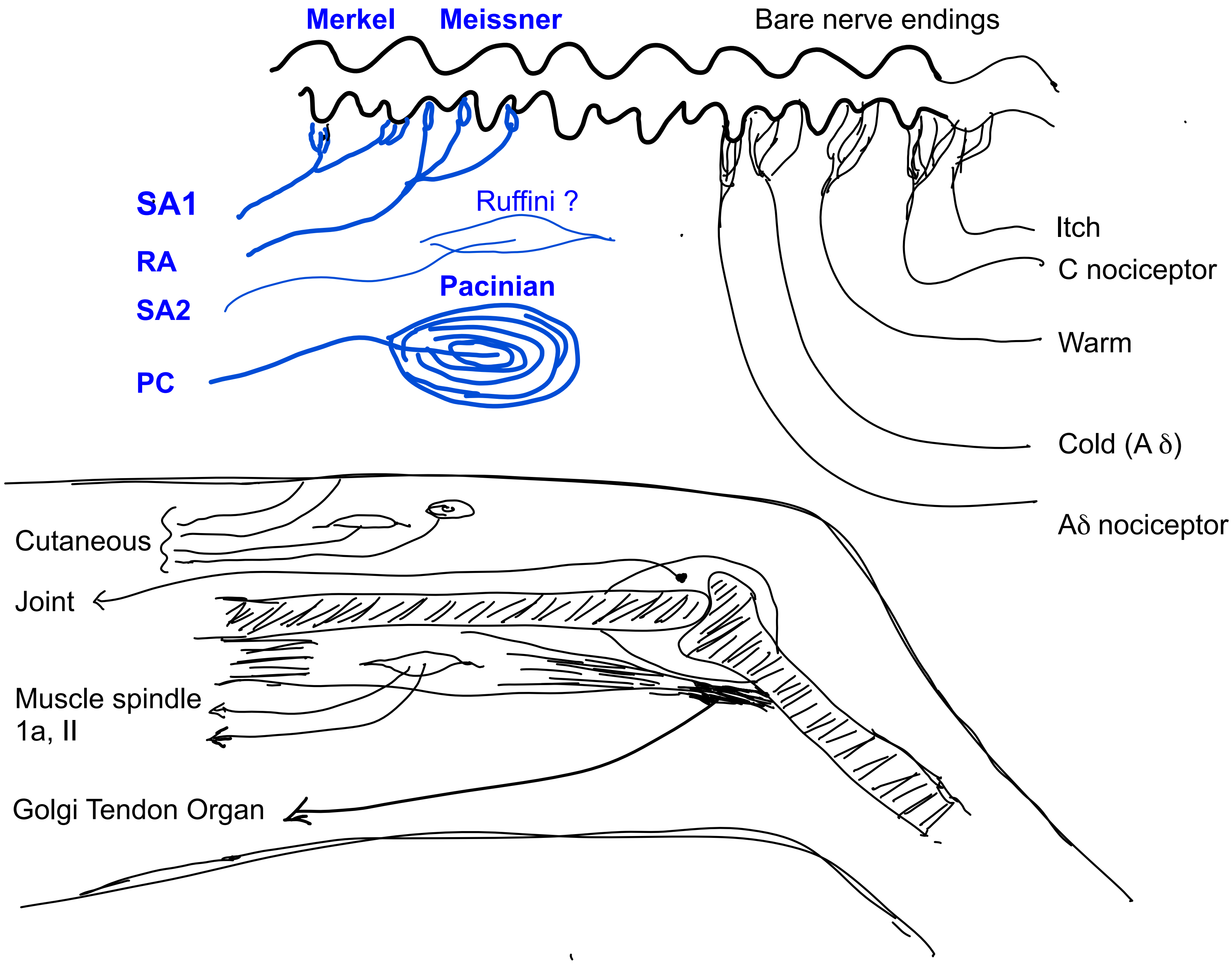
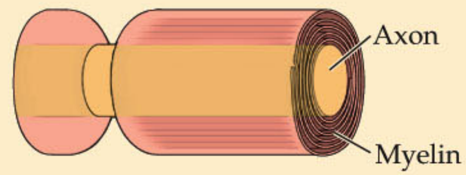
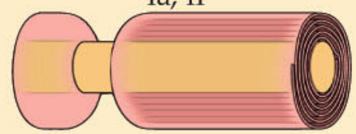
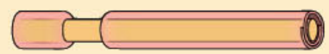


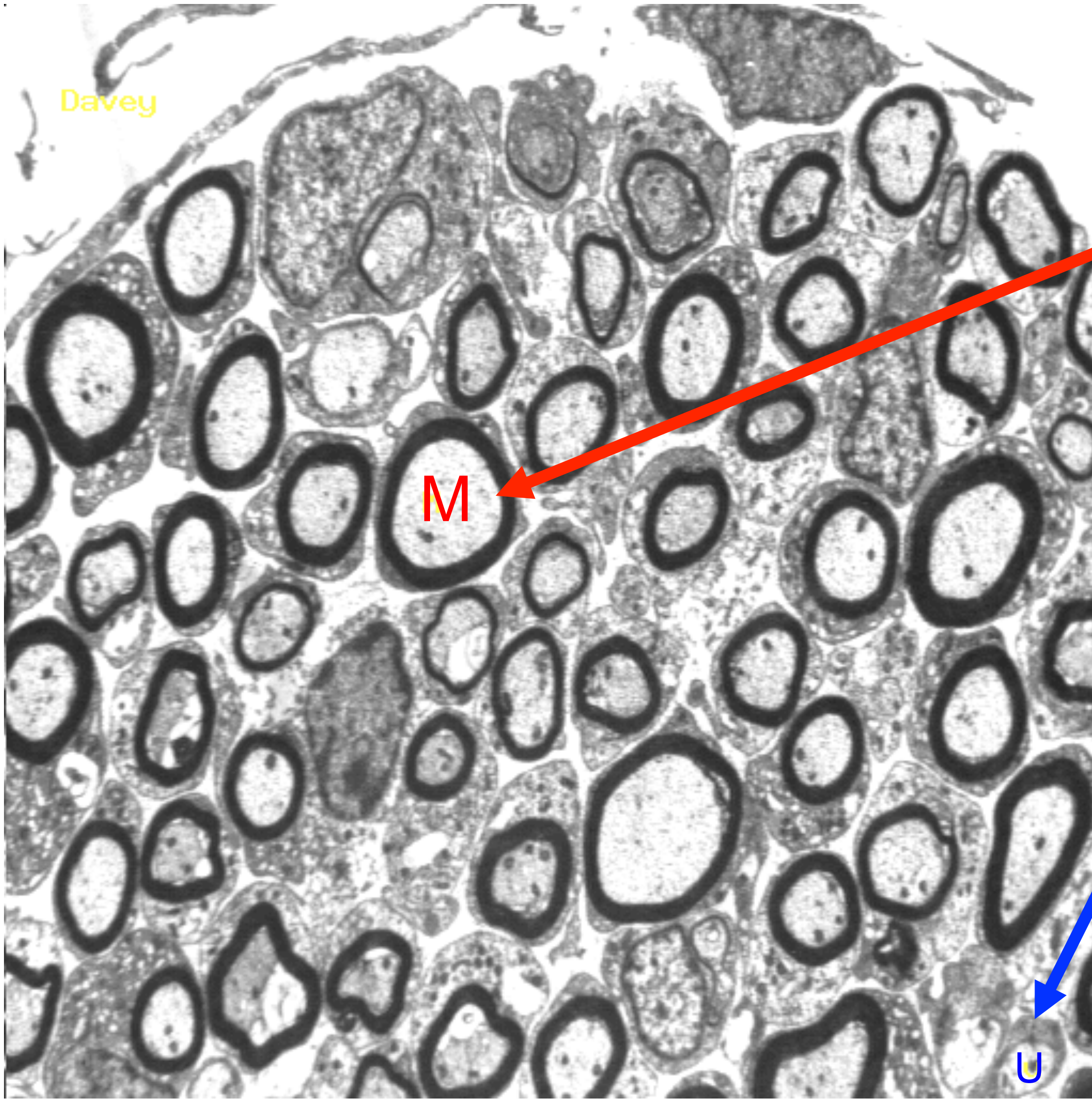
TABLE 9.1 Somatic Sensory Afferents that Link Receptors to the Central Nervous System

Sensory function	Receptor type	Afferent axon type[a]	Axon diameter	Conduction velocity
Proprioception	Muscle spindle	 Ia, II	13–20 μm	80–120 m/s
Touch	Merkel, Meissner, Pacinian, and Ruffini cells	 Aβ	6–12 μm	35–75 m/s
Pain, temperature	Free nerve endings	 Aδ	1–5 μm	5–30 m/s
Pain, temperature, itch	Free nerve endings	 C	0.2–1.5 μm	0.5–2 m/s

[a]During the 1920s and 1930s, there was a virtual cottage industry classifying axons according to their conduction velocity. Three main categories were discerned, called A, B, and C. A comprises the largest and fastest axons, C the smallest and slowest. Mechanoreceptor axons generally fall into category A. The A group is further broken down into subgroups designated α (the fastest), β, and δ (the slowest). To make matters even more confusing, muscle afferent axons are usually classified into four additional groups—I (the fastest), II, III, and IV (the slowest)—with subgroups designated by lowercase roman letters!

(After Rosenzweig et al., 2005.)

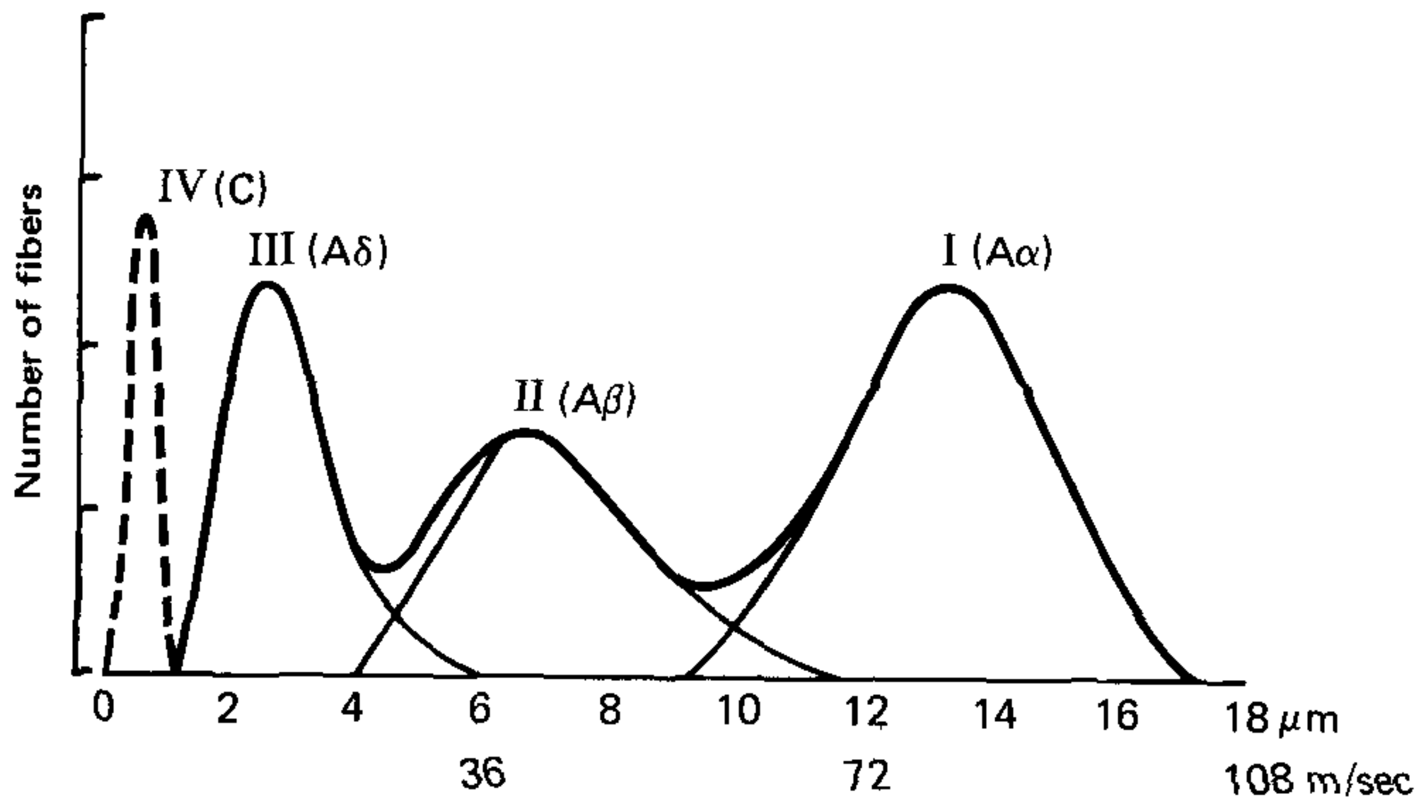
Afferent nerves differ in diameter and myelination and conduction velocity



M=myelinated

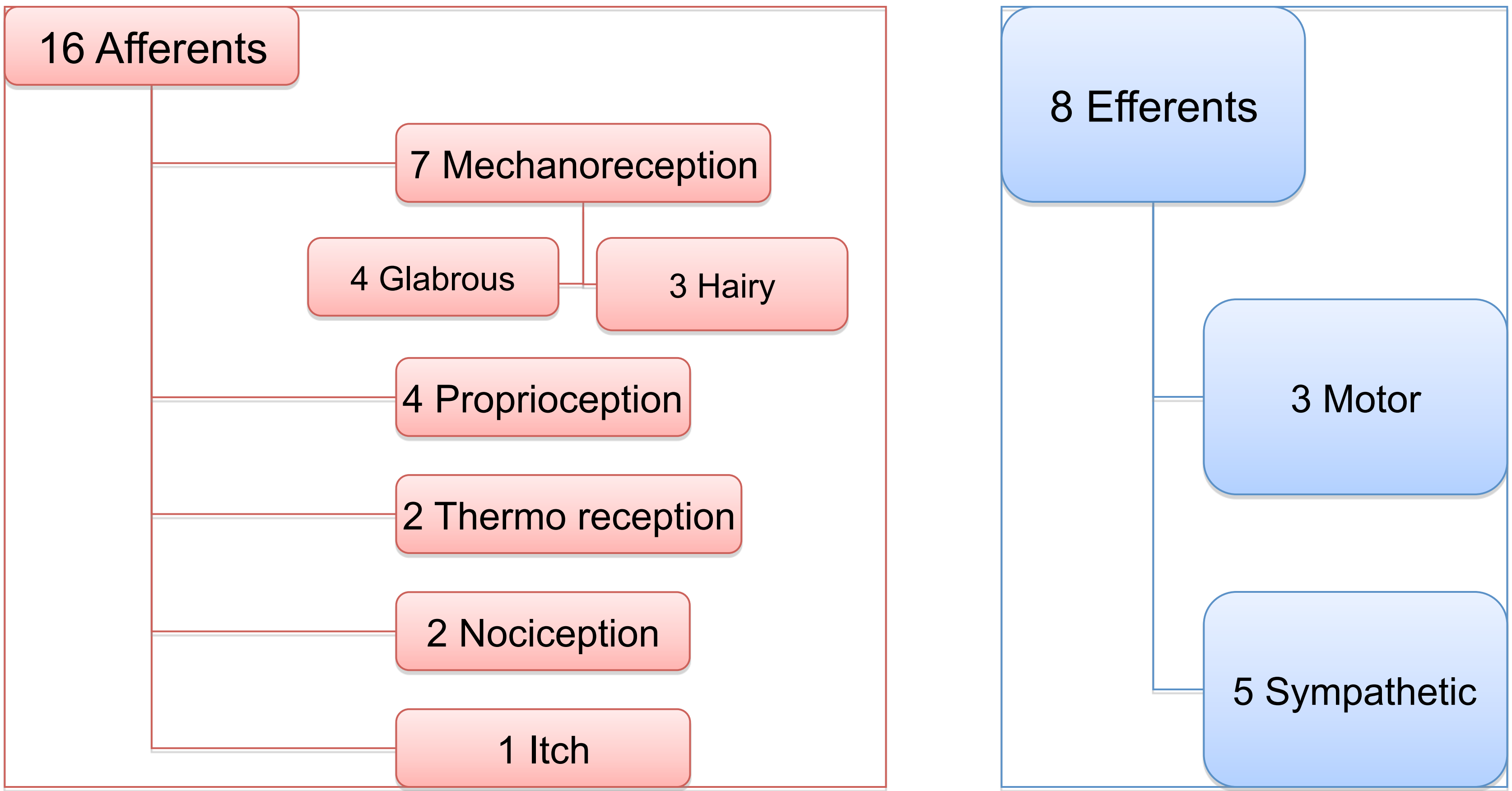
U = unmyelinated

Afferent nerves differ in diameter and myelination and conduction velocity



Diameter / Conduction velocity

24 different fiber types in a peripheral nerve

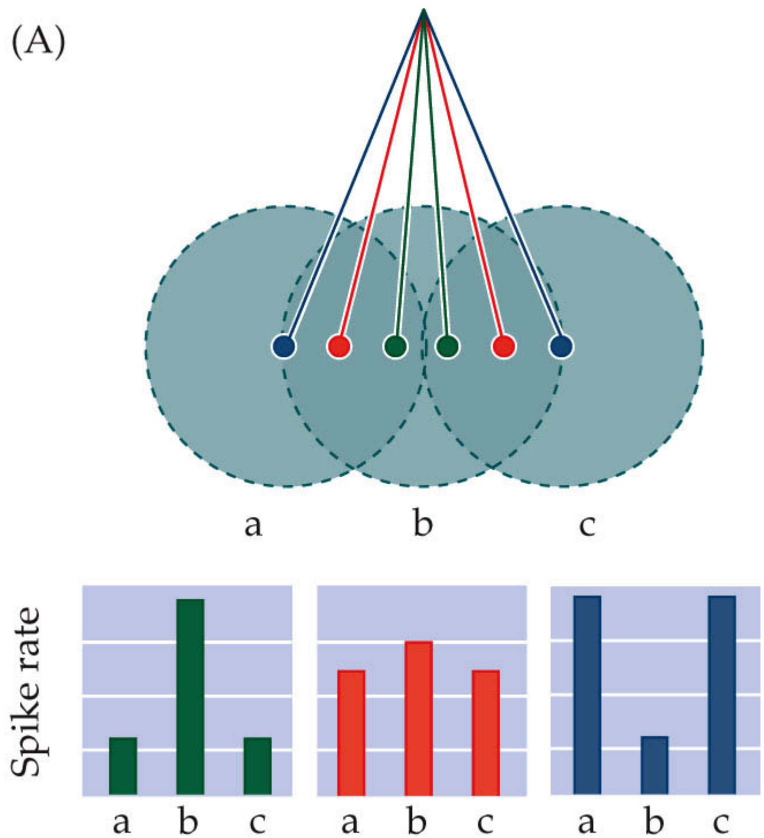


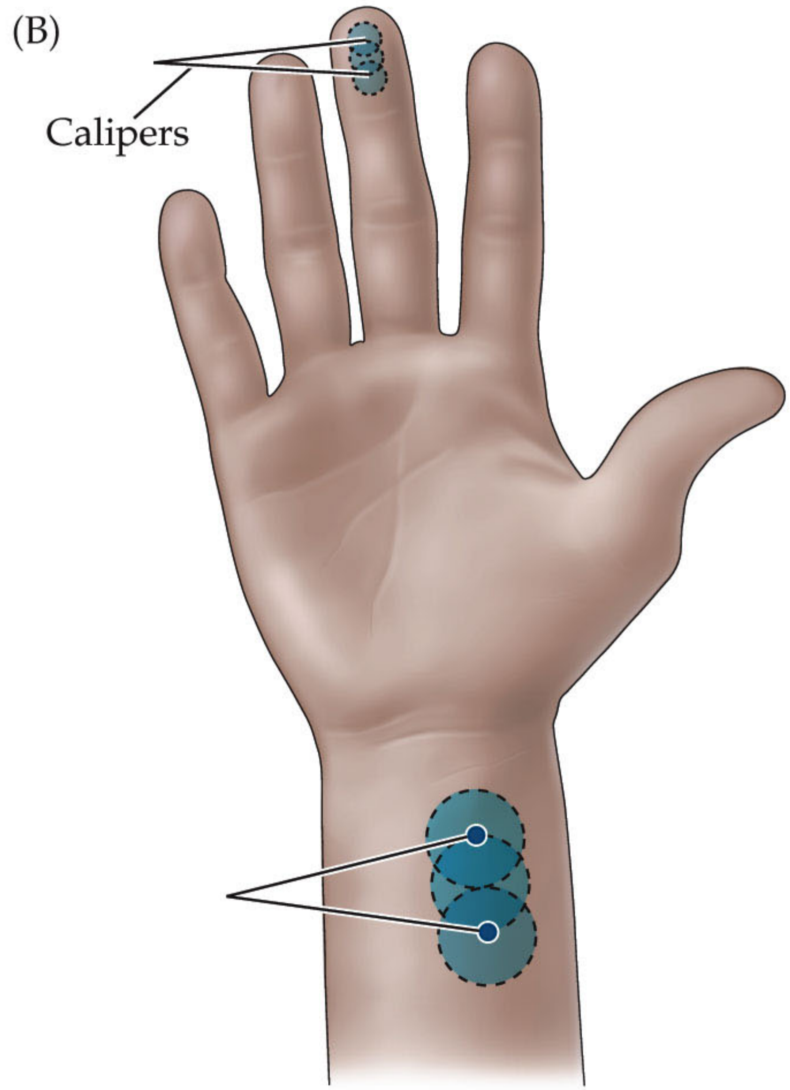
Different afferent fibers have different sensory endings

- Allows afferent fibers to respond to specific environmental energies.
- Specificity is based on selectivity of receptor channels
- Basis for modality segregation
- Responsible for different aspects of perception

Form and Texture Processing

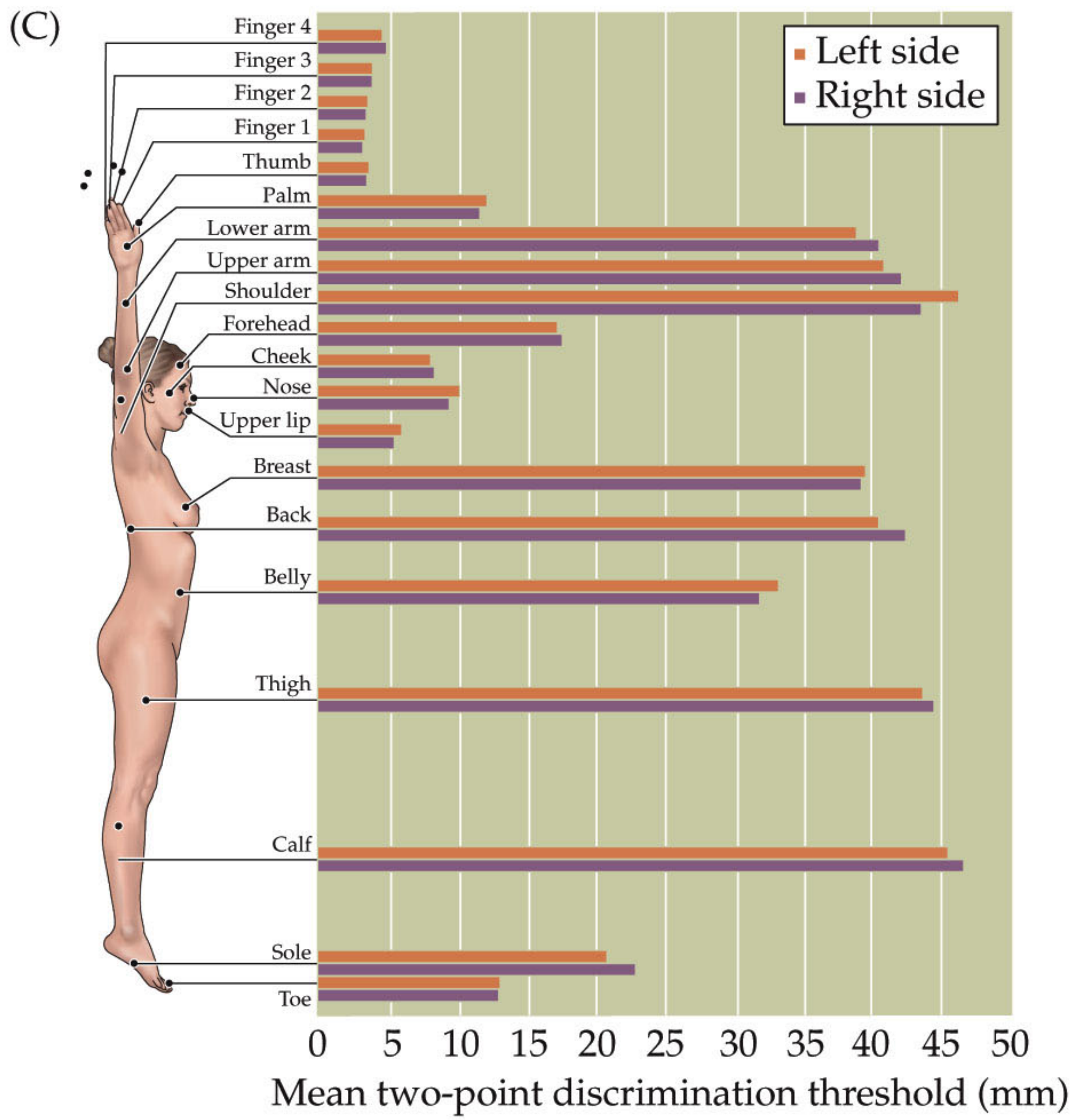
Receptive fields and two-point discrimination threshold





***NEUROSCIENCE*, *Fourth Edition*, Figure 9.3 (Part 1)**

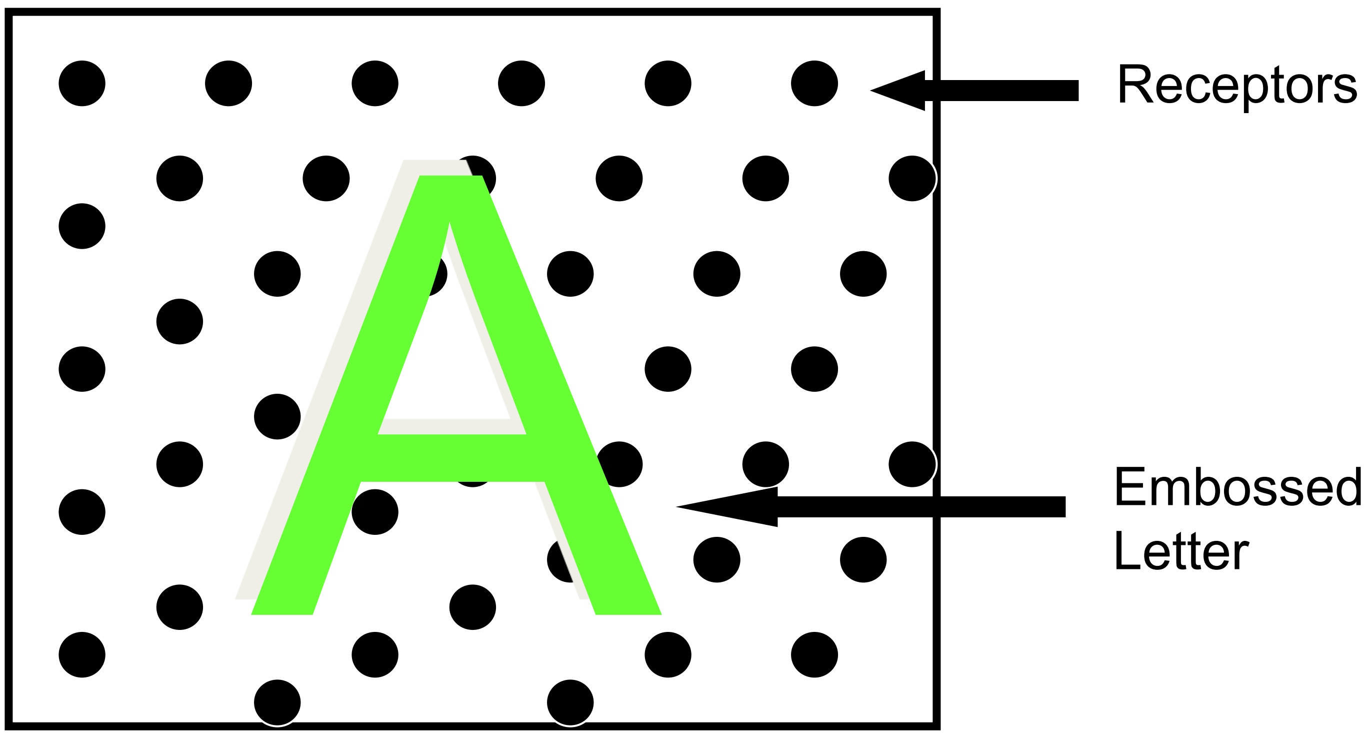
Receptive fields and two-point discrimination threshold



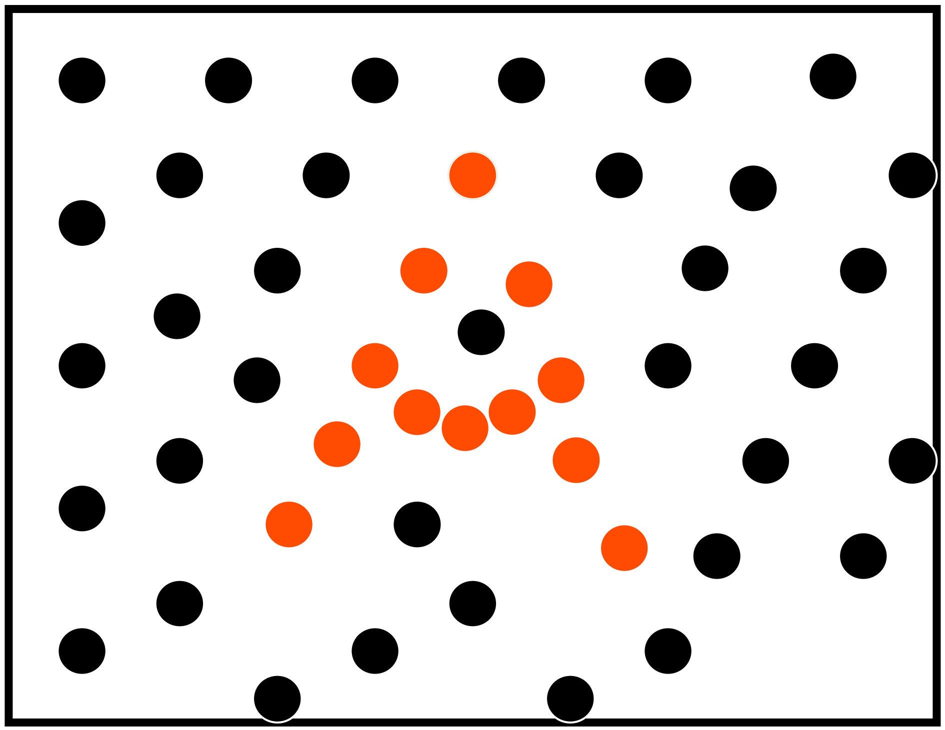
***NEUROSCIENCE*, *Fourth Edition*, Figure 9.3 (Part 2)**

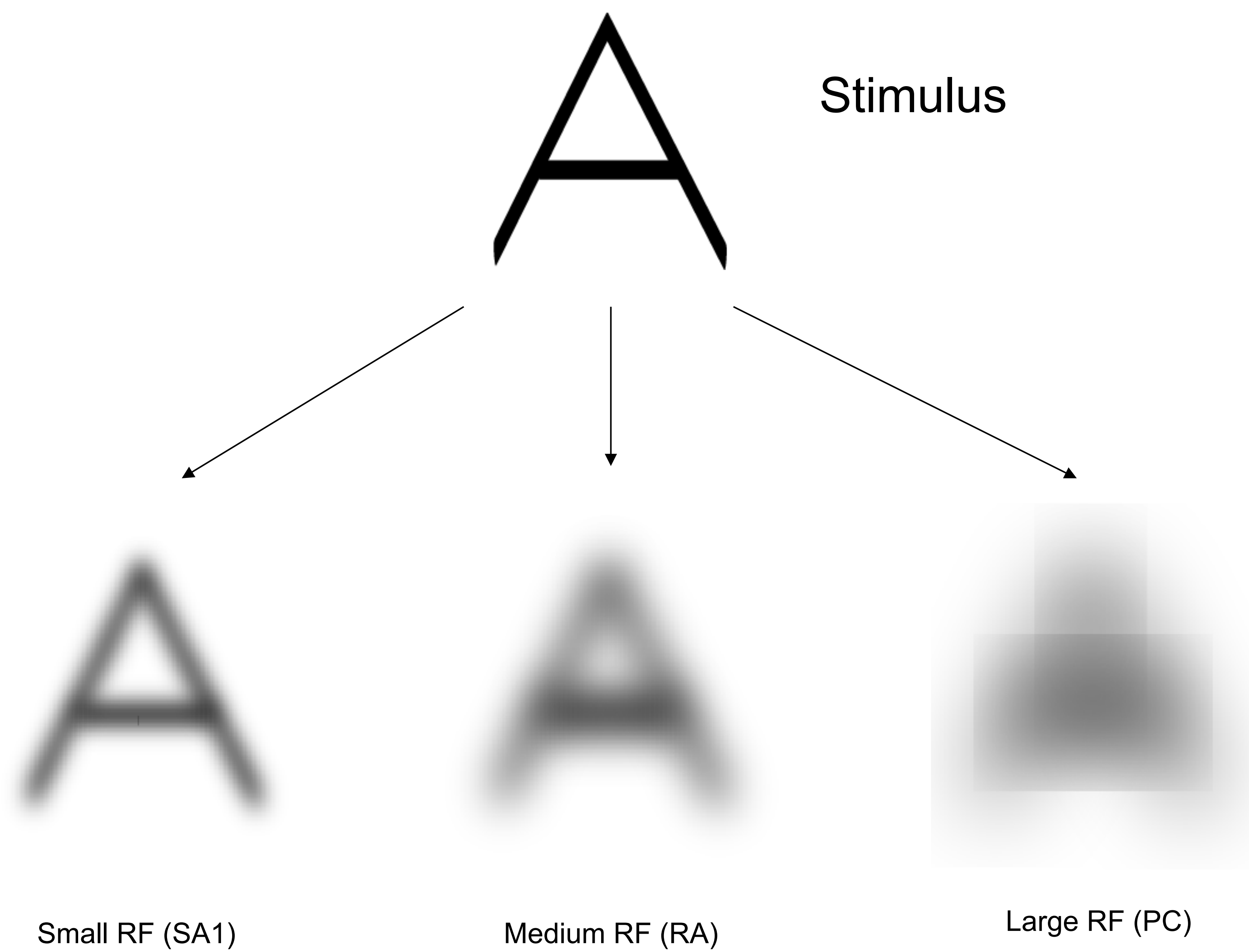
Form Processing

• Spatial processing - Activity across a population



Skin surface




Stimulus
Small RF (SA1)
Medium RF (RA)
Large RF (PC)

Spatial codes

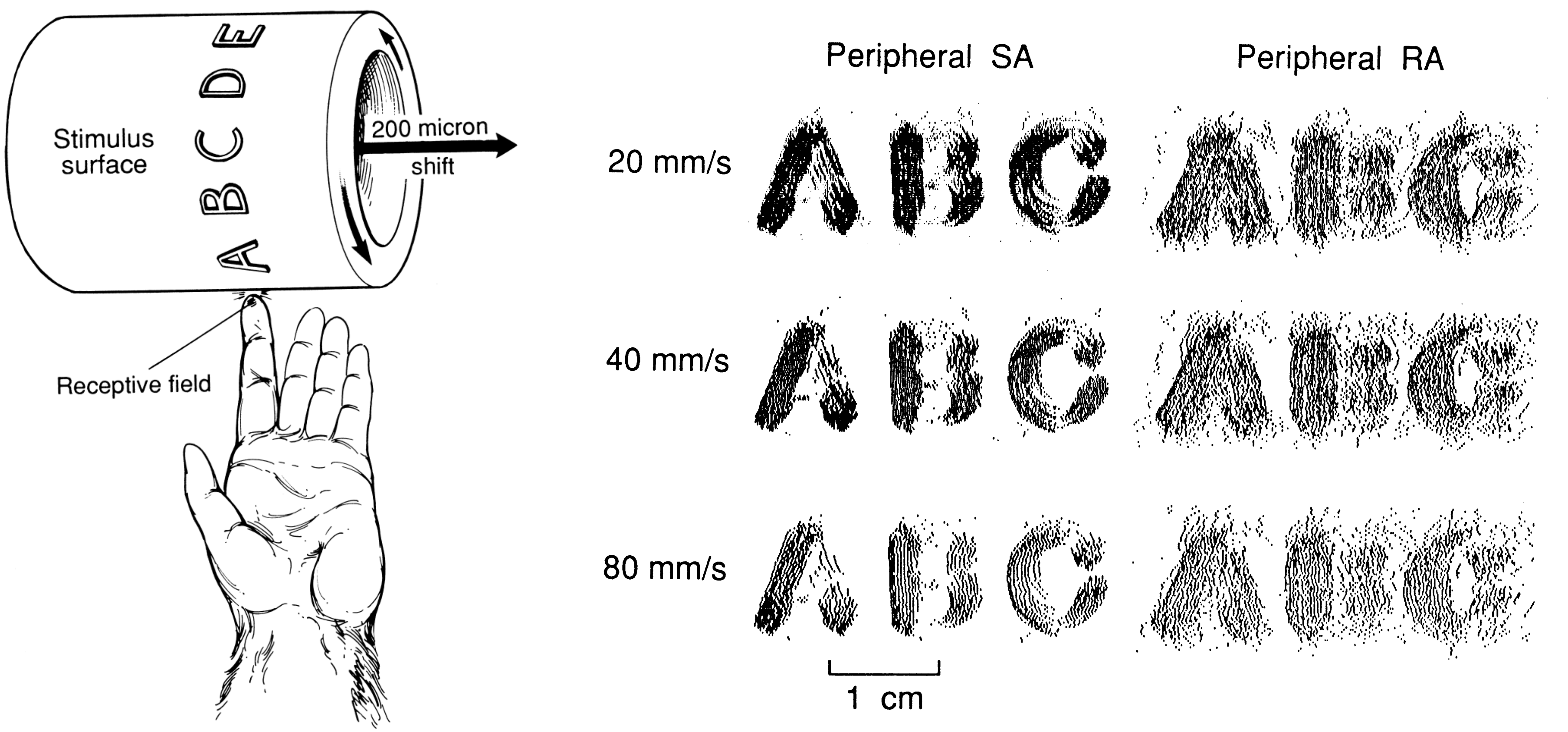
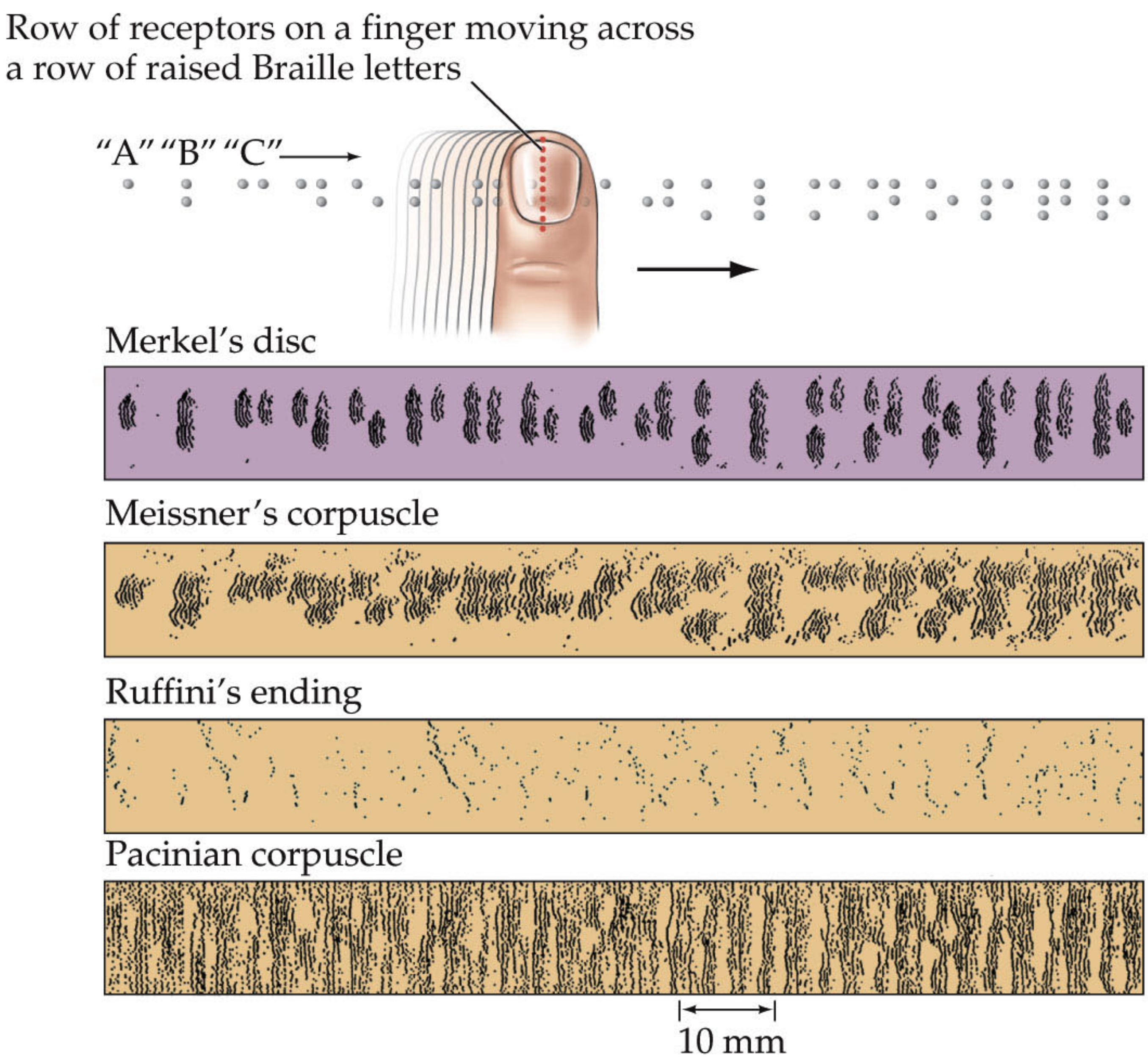


Figure 9.6 Simulated activity patterns in different mechanosensory afferents as Braille is read



Slowly adapting

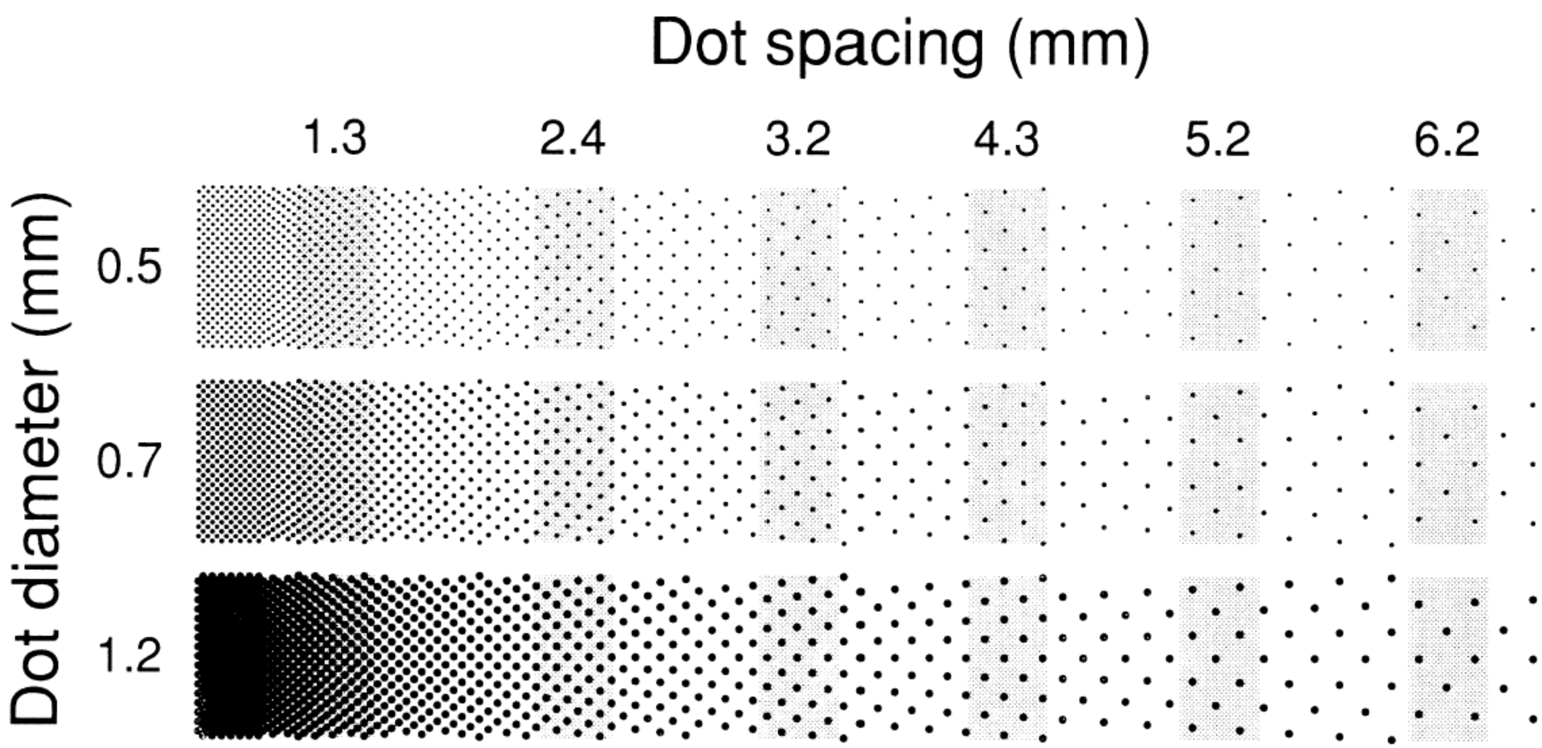
NEUROSCIENCE, Fourth Edition, Figure 9.6

Form and Texture

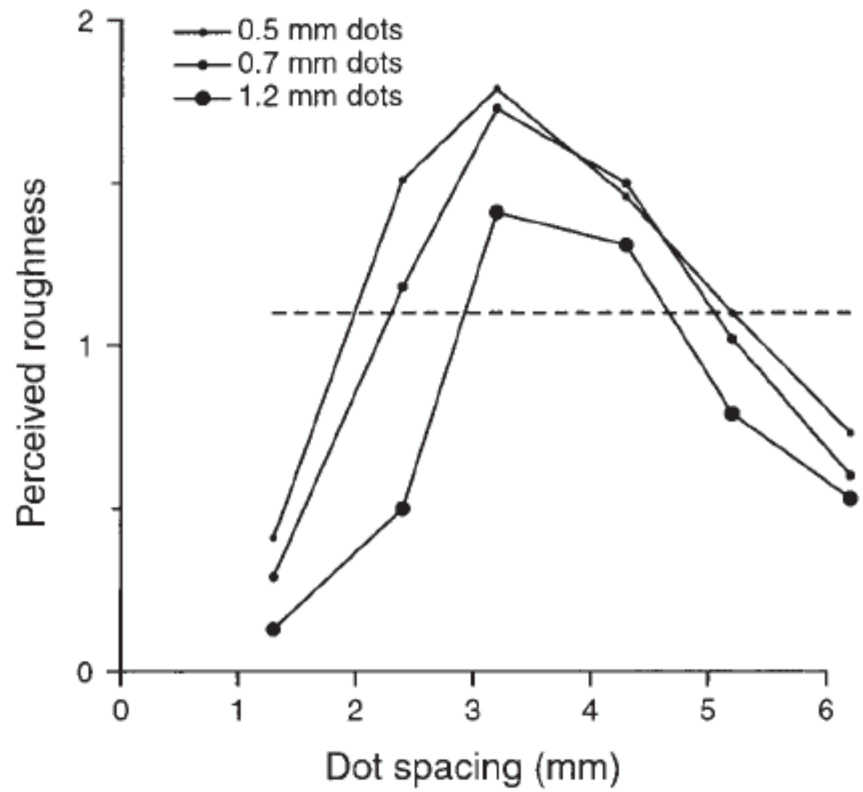
- Both form and texture perception depend on spatial codes

Correlation of psychophysics and Neurophysiology: Neural mechanisms of tactile roughness

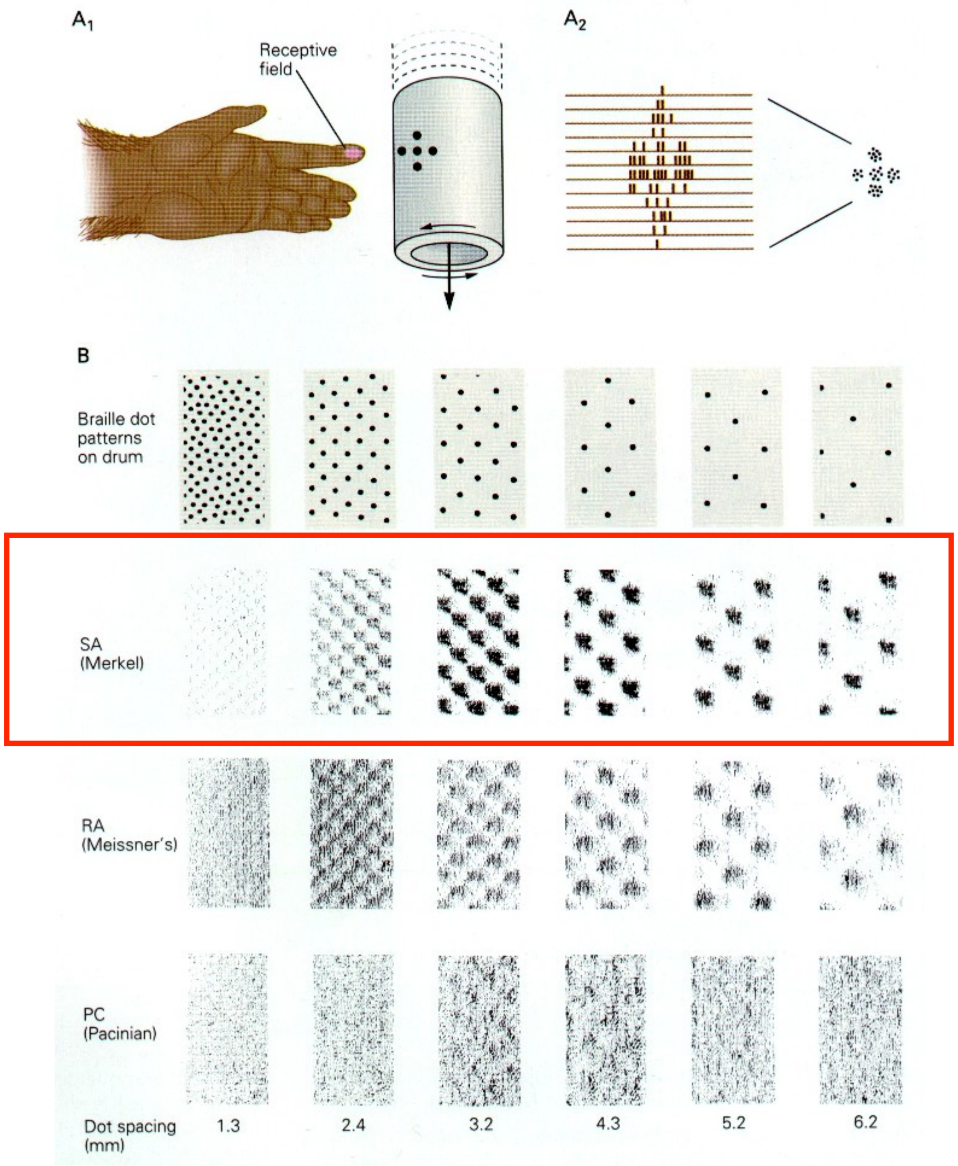
Stimulus –Experiment 1



Psychophysics

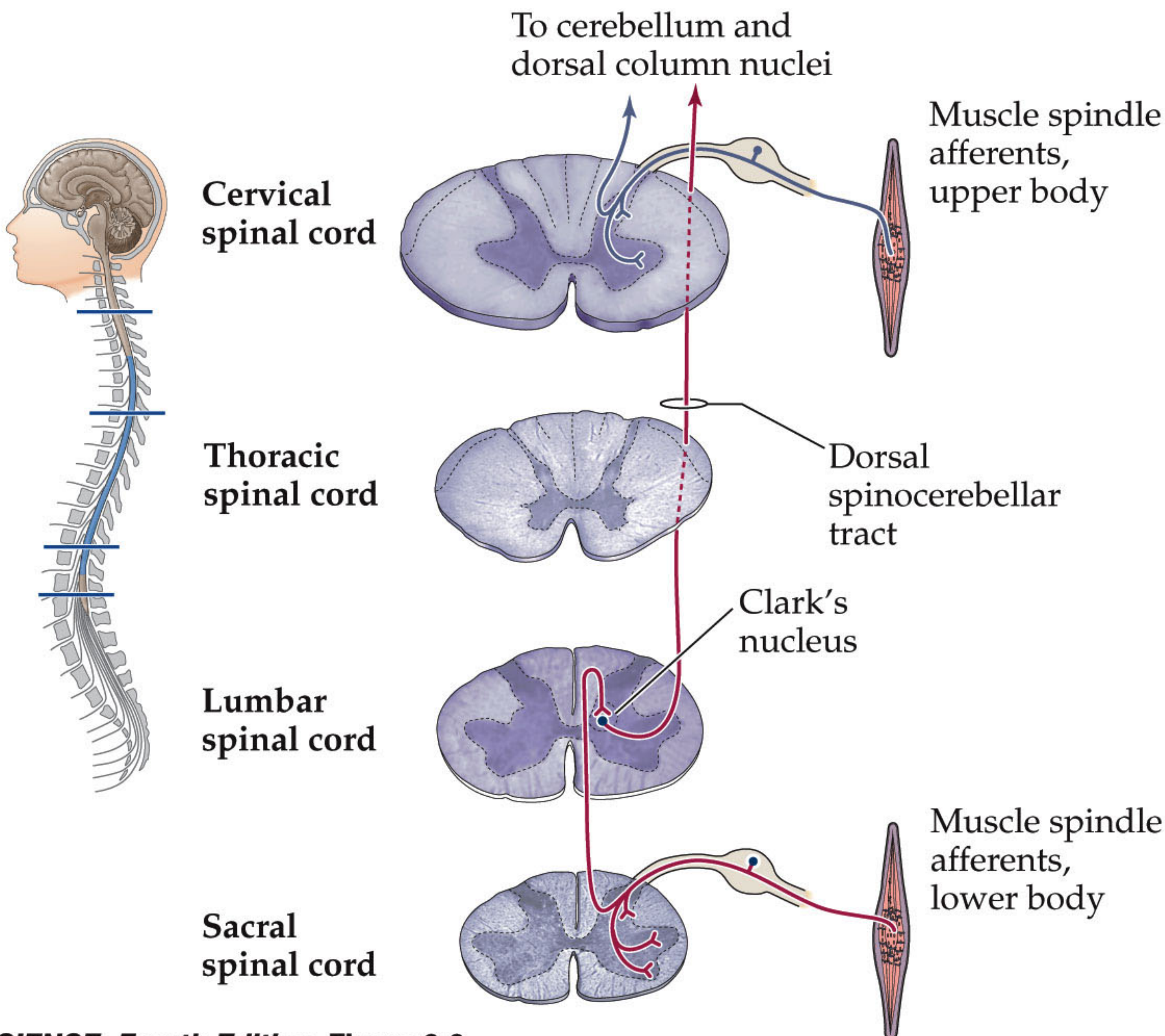


Signal processing properties of neurons are linked to their RF properties



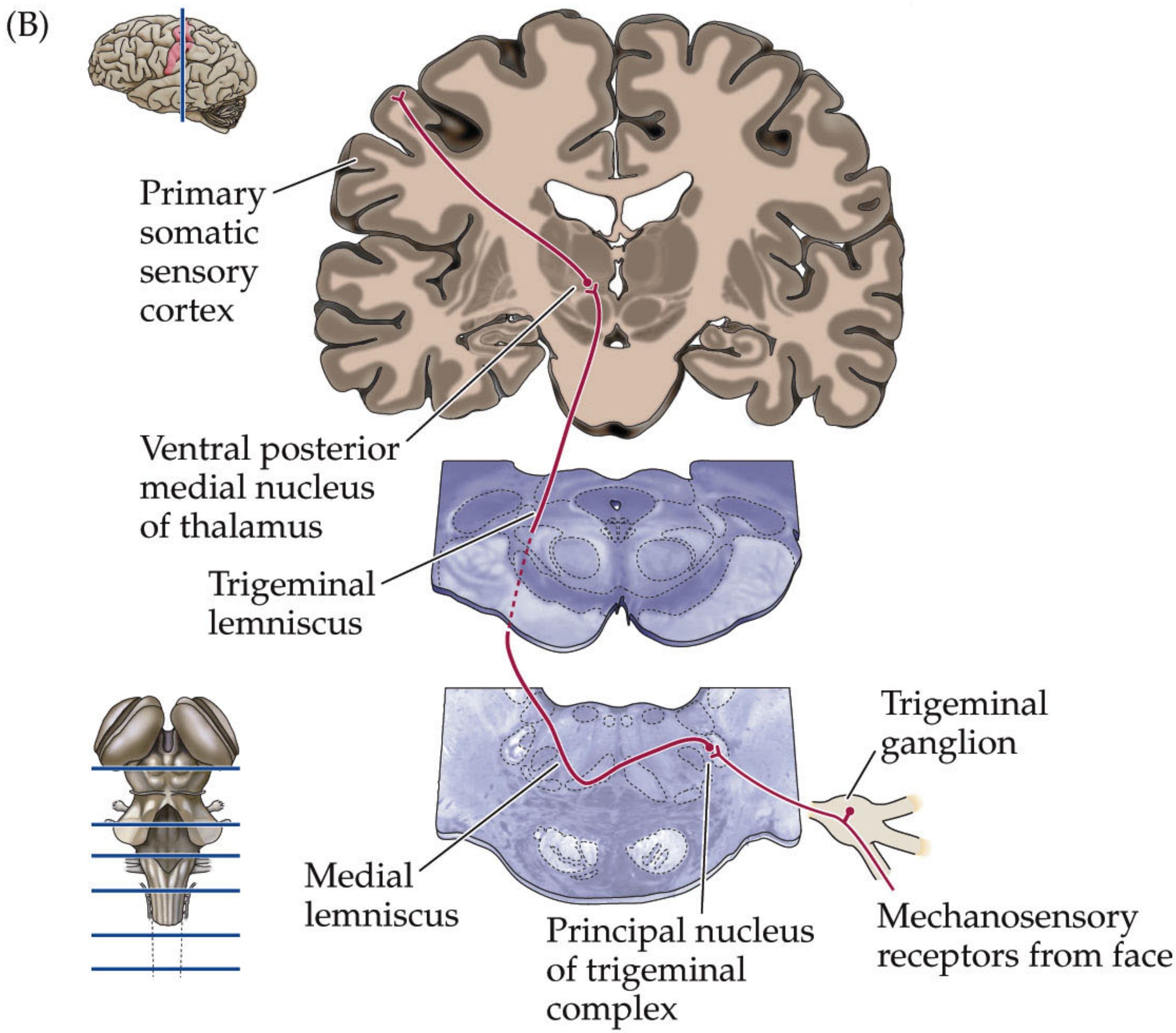
Cortical Representations

Figure 9.9 Proprioceptive pathways for the upper and lower body



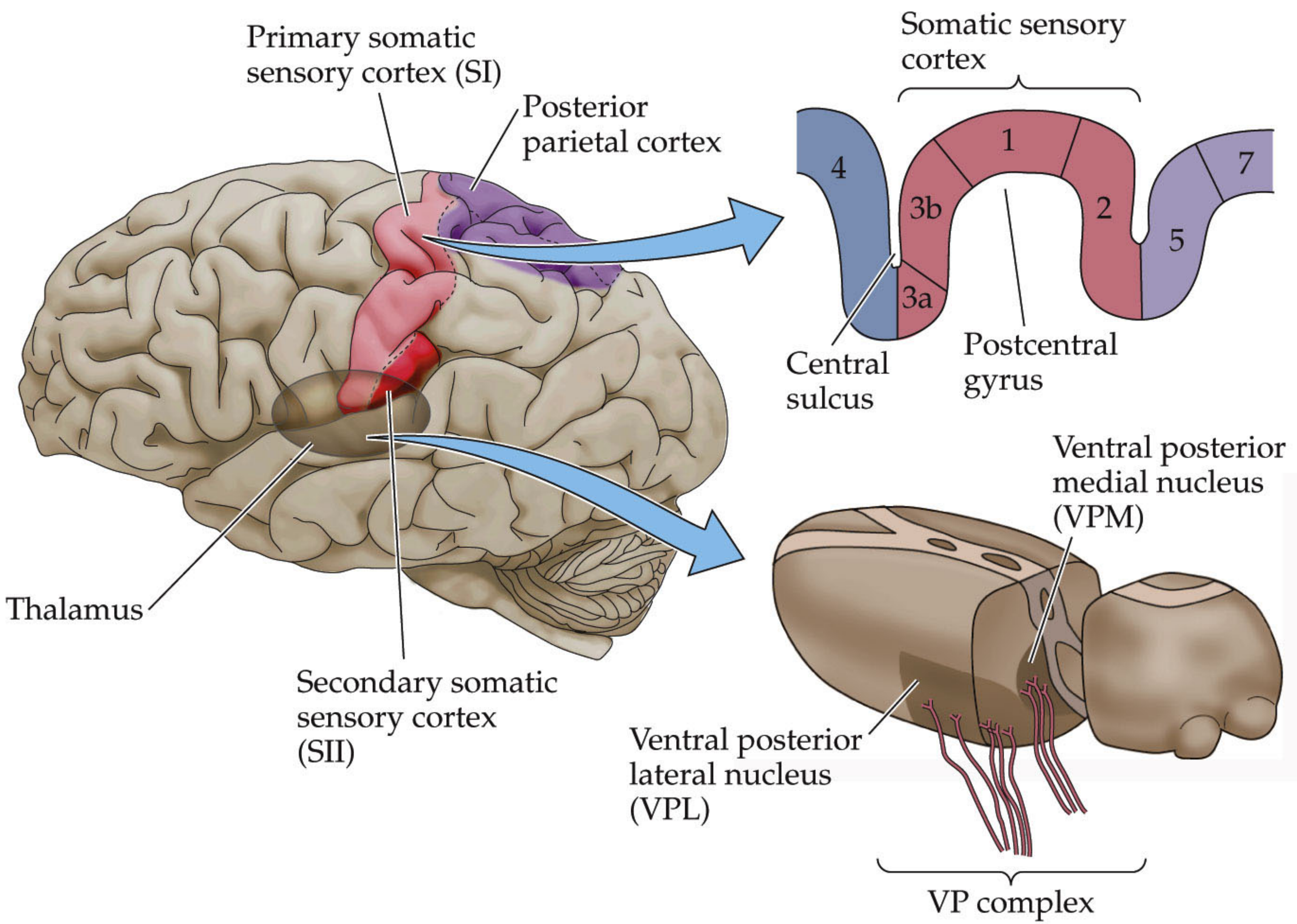
NEUROSCIENCE, *Fourth Edition*, Figure 9.9

Figure 9.8 Schematic representation of the main mechanosensory pathways (Part 2)



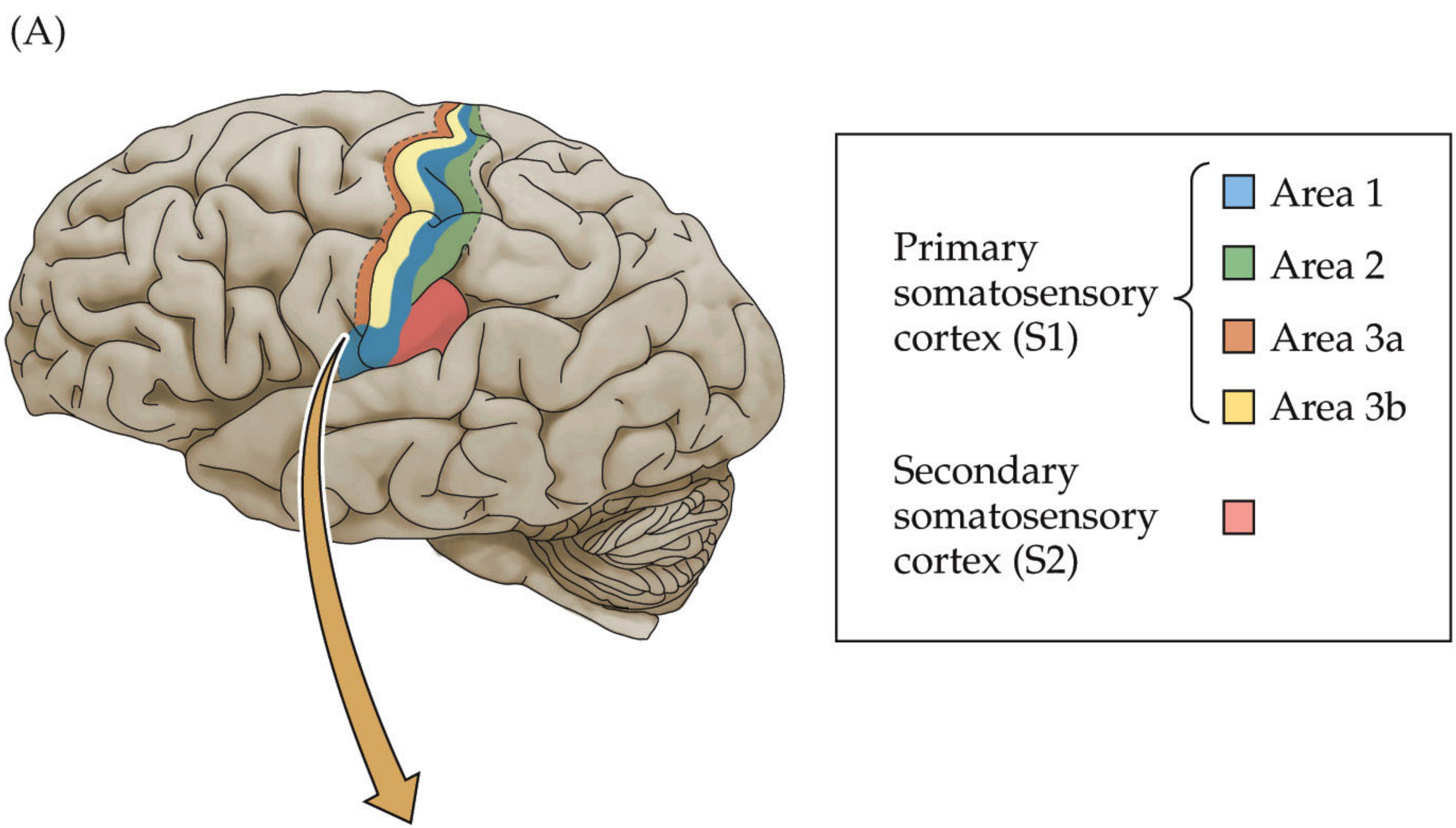
NEUROSCIENCE, Fourth Edition, Figure 9.8 (Part 2)

Figure 9.10 Somatic sensory portions of the thalamus and their cortical targets in postcentral gyrus



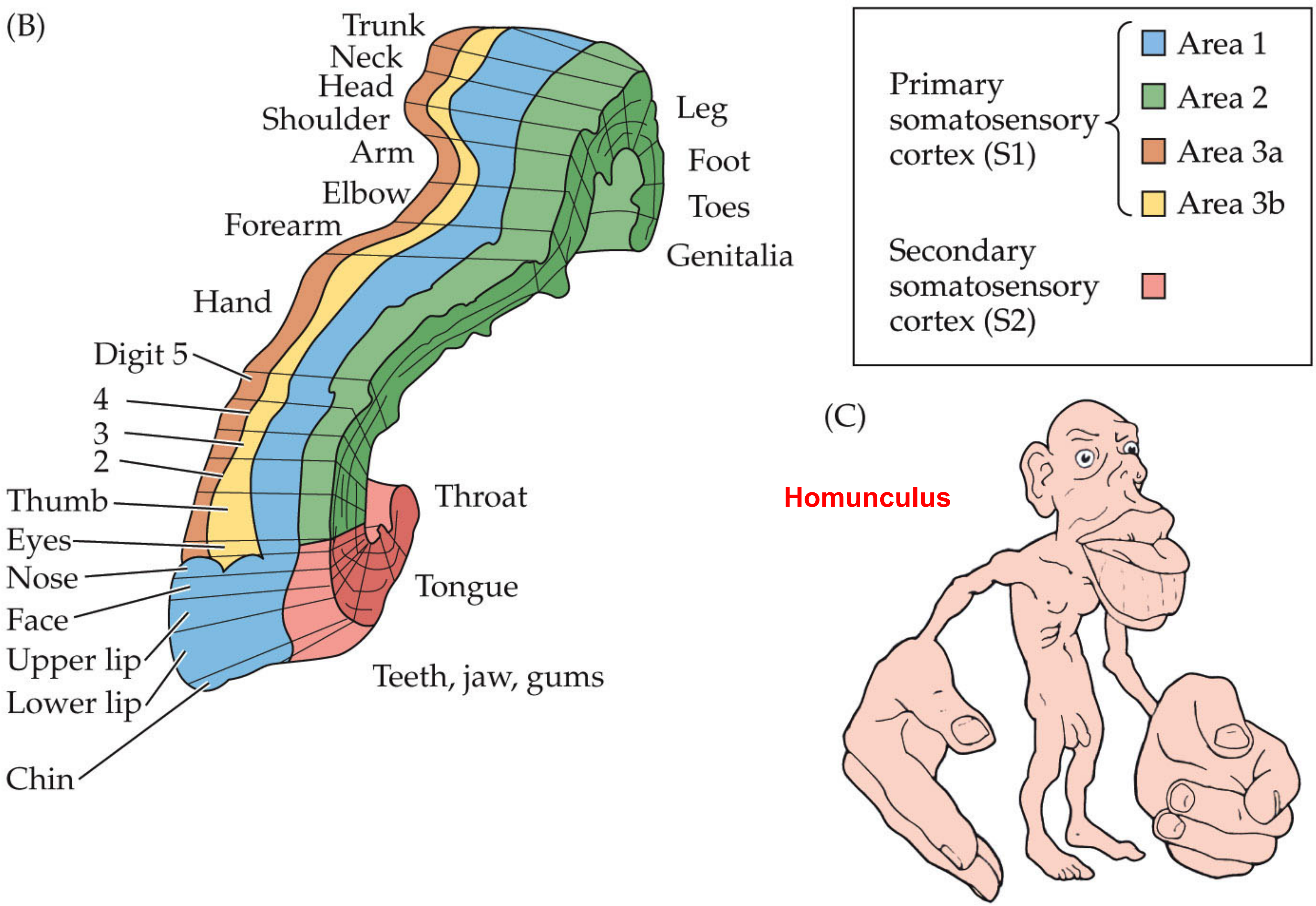
***NEUROSCIENCE*, *Fourth Edition*, Figure 9.10**

Figure 9.11 Somatotopic order in the human primary somatic sensory cortex (Part 1)



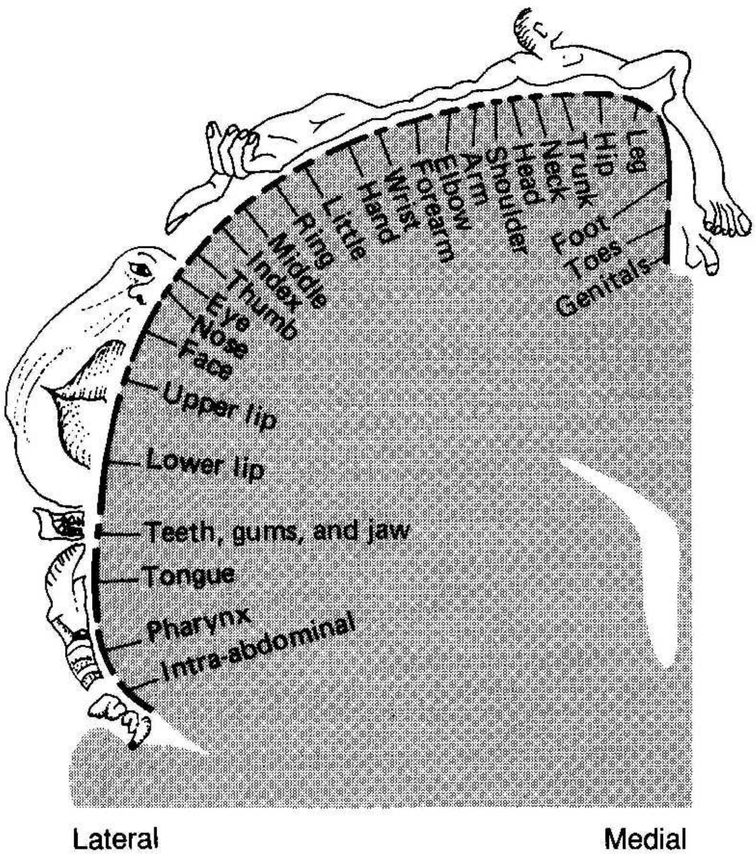
***NEUROSCIENCE*, *Fourth Edition*, Figure 9.11 (Part 1)**

Figure 9.11 Somatotopic order in the human primary somatic sensory cortex (Part 2)

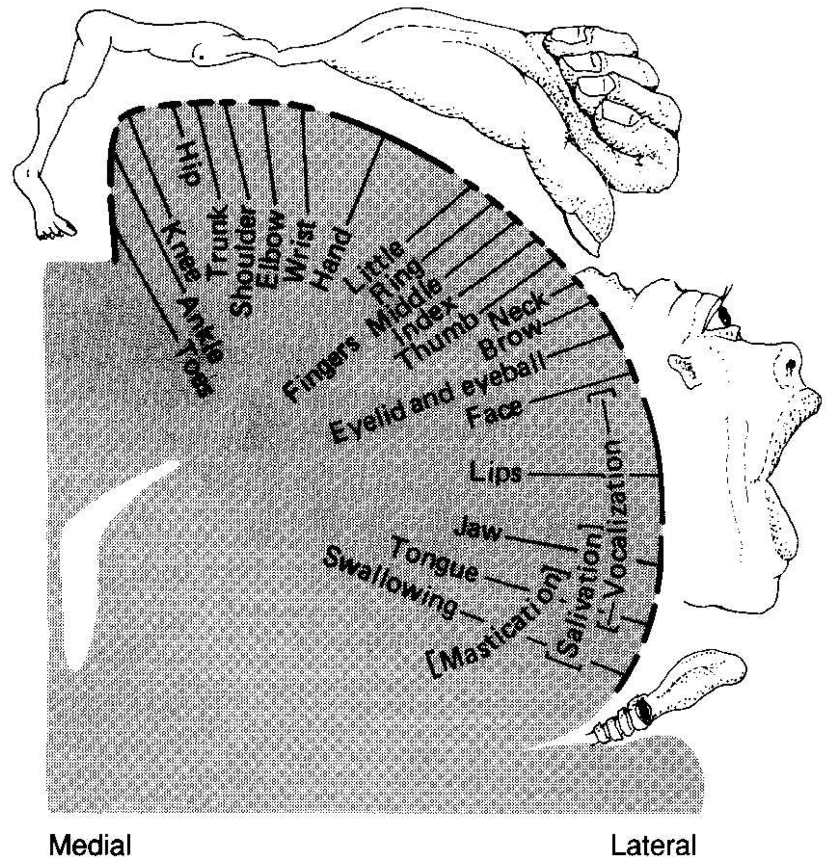


NEUROSCIENCE, *Fourth Edition*, Figure 9.11 (Part 2)

Sensory Homunculus



Motor Homunculus

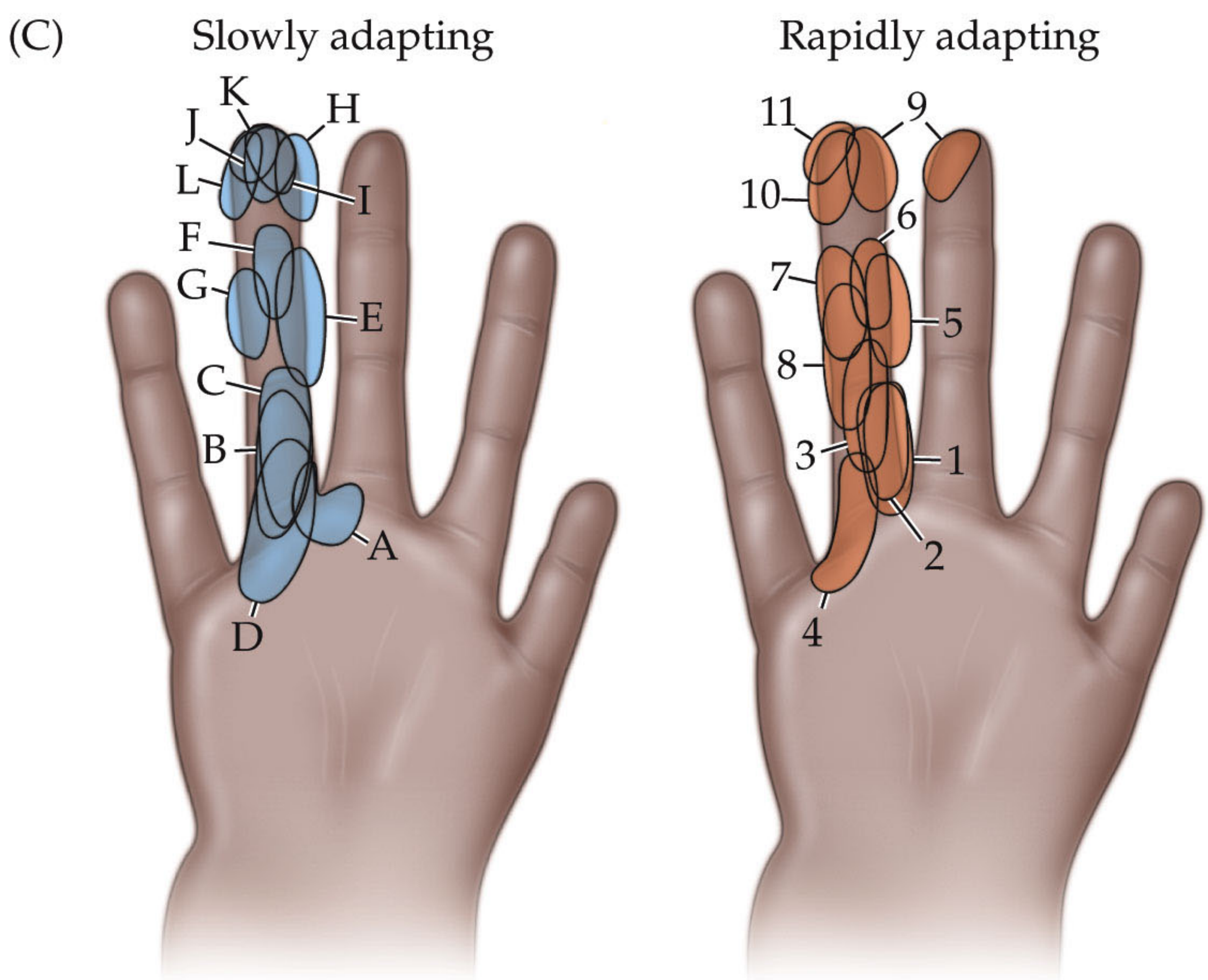


Plasticity

What is Plasticity?

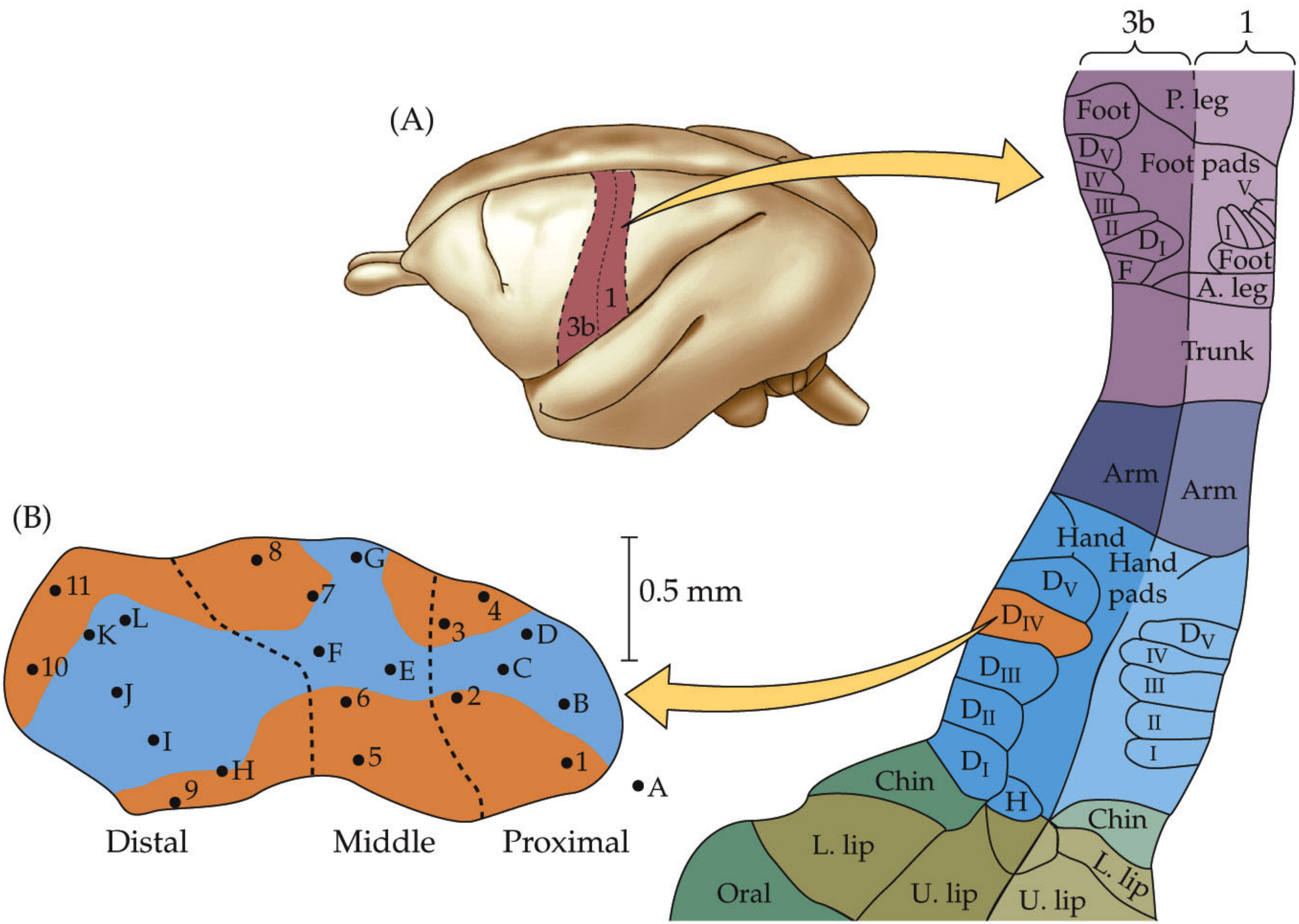
- Plasticity refers to the relatively long-lasting modifications in neuronal response that accompany changes in environmental stimuli
- Topographic changes in sensory representation
- Plasticity can be observed in these conditions:
  - Response to injury
  - Normal learning

Figure 9.13 Neurons in primary somatosensory cortex form functionally distinct columns (Part 2)



NEUROSCIENCE, Fourth Edition, Figure 9.13 (Part 2)

Figure 9.13 Neurons in primary somatosensory cortex form functionally distinct columns (Part 1)



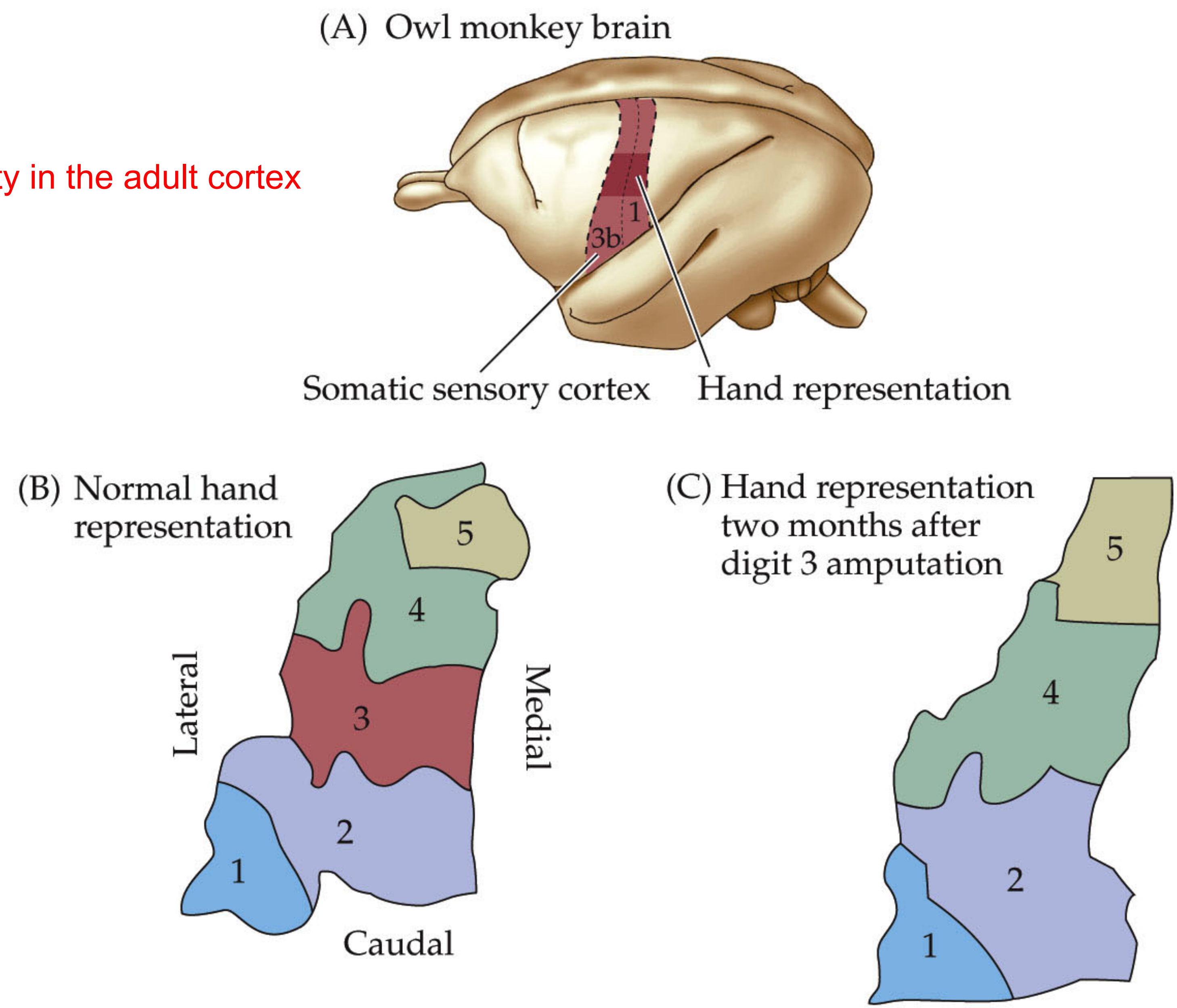
NEUROSCIENCE, Fourth Edition, Figure 9.13 (Part 1)

Amputation

- What happens to these maps after one or more digits are amputated?

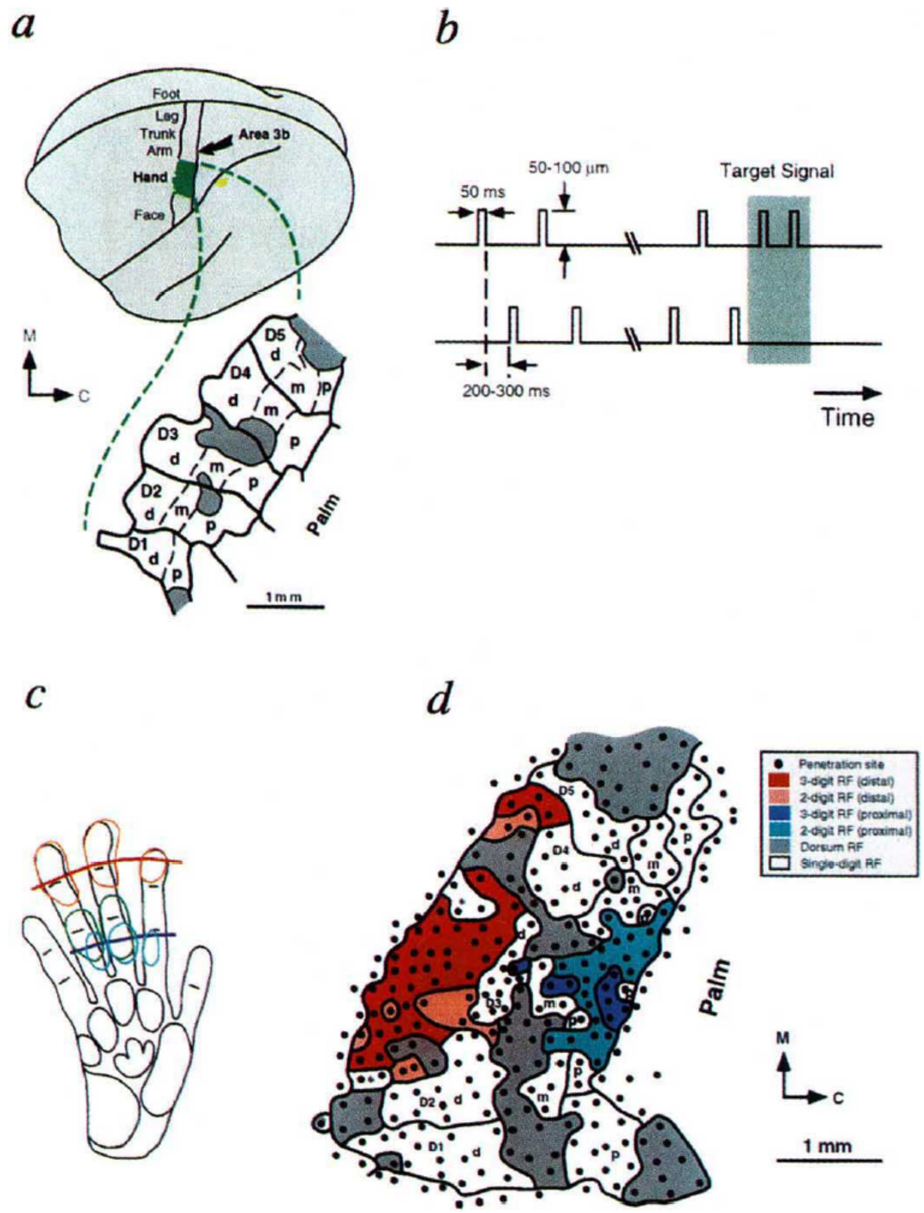
Figure 9.14 Changes in somatic sensory cortex of an owl monkey following amputation of a digit

Plasticity in the adult cortex



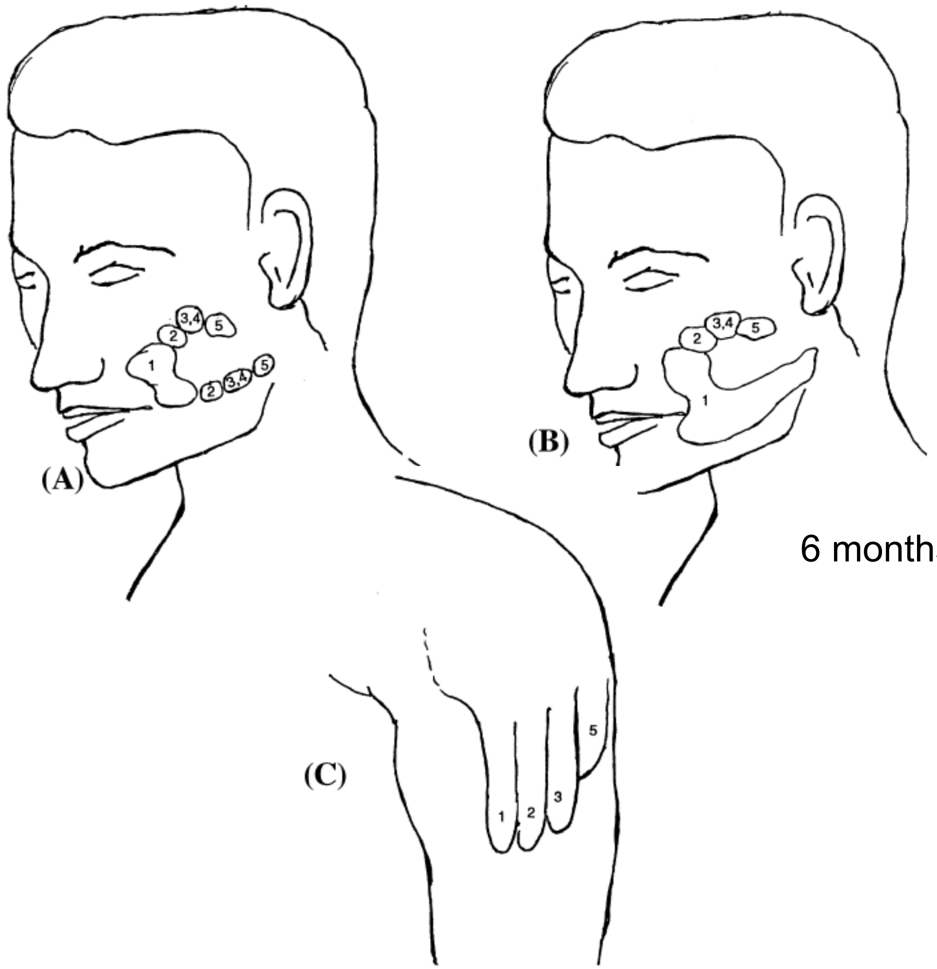
NEUROSCIENCE, Fourth Edition, Figure 9.14

Cortical plasticity is likely the neural basis of skill learning



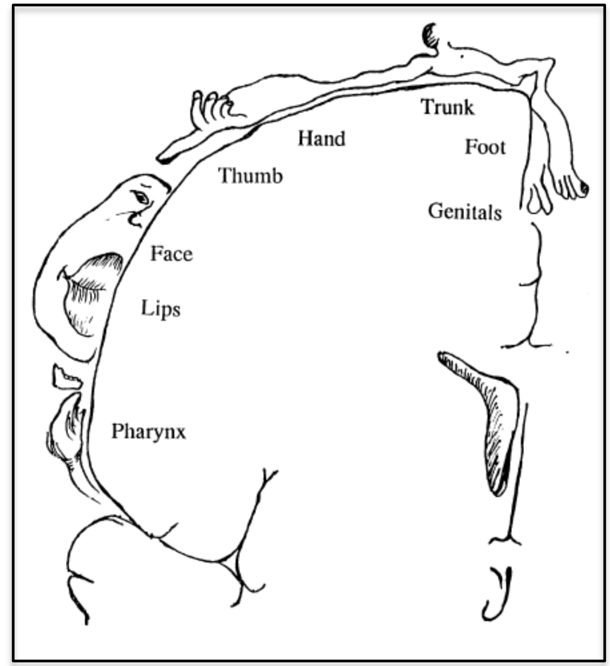
Wang et al. (*Nature*, 1995)

Phantom limbs



6 months later

Amputated arm

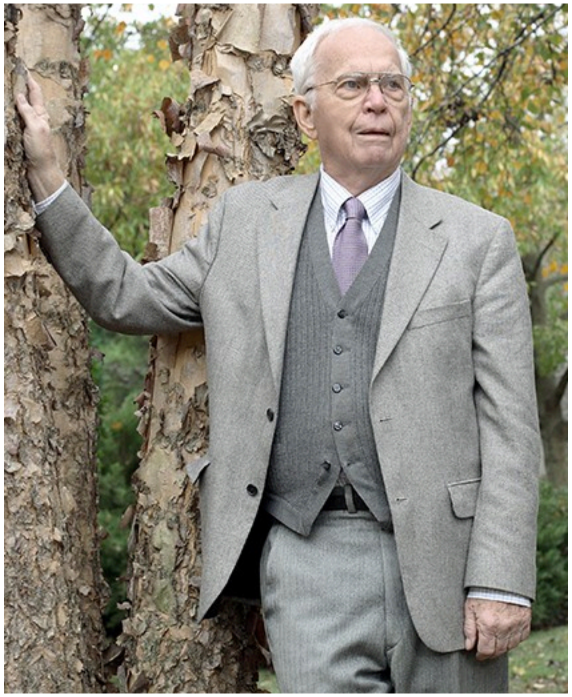


Prof. Kenneth O. Johnson
(1938-2005)

Kenneth Johnson, Professor of Neuroscience and Biomedical Engineering and Director of the Krieger Mind/Brain Institute of the Johns Hopkins University, passed away on May 15, 2005. Ken was an outstanding scientist who devoted his career towards understanding the neural mechanisms of perception. He was one of the first Ph.D. students to receive a degree from the Biomedical Engineering Department of the Johns Hopkins University. Throughout his career he was a strong advocate for using quantitative methods to understand how the brain works.

The late 1960s was an extremely exciting time in neuroscience. The method of single unit recording was in its infancy and with Vernon Mountcastle, who was Ken's thesis advisor at Hopkins, Ken decided to study the neural basis of behavior. Vernon had shown that the neural mechanisms underlying behavior could be studied directly and he had pioneered a new approach of studying the brain by combining psychophysical studies in humans with neurophysiological studies in non-human primates. Ken adopted this approach to use in his studies for his entire career.

Professor Vernon Mountcastle



The career of Dr.Vernon Mountcastle, professor emeritus of neuroscience at Johns Hopkins, began with his admission to Hopkins medical school in 1938. Brain research has come a long way since Vernon Mountcastle began his pioneering work during the 1950s.

"You can see the brain, in three dimensions," Mountcastle says. "It's so dramatic. You can follow the blood flow and you can determine whether there are lesions in vessels or lesions in the brain. It's a whole new world."

Yet, the brain still harbors a huge reservoir of mysteries, a gulf of unknown and exciting territories that may take another century to fully traverse, he says. For example, scientists are far from understanding how the brain accomplishes the higher functions, such as consciousness and advanced analytical thinking, says Mountcastle, who influenced the creation of the Krieger Mind/Brain Institute at Johns Hopkins in 1990.

More than 30 years ago, Mountcastle discovered a fundamental truth about brain physiology: that cells performing like functions are connected in intricate "modules" arranged in vertical columns. The finding was controversial at the time because scientists had thought that brain cells, or neurons, were arranged only in horizontal layers. Although his work pertained specifically to the portion of the brain that handles the sense of touch, other scientists have since discovered the same modular design throughout the cerebral cortex--sometimes commonly referred to as gray matter--the center of intelligence, perception and motor skills.

Suggested readings:

"*Neuroscience*" textbook, Chapter 9: The somatic sensory system: Touch and proprioception

Ramachandran VS, Hirstein W. The perception of phantom limbs. The D. O. Hebb lecture. Brain. 1998 Sep;121 (Pt 9): 1603-30. [Review]