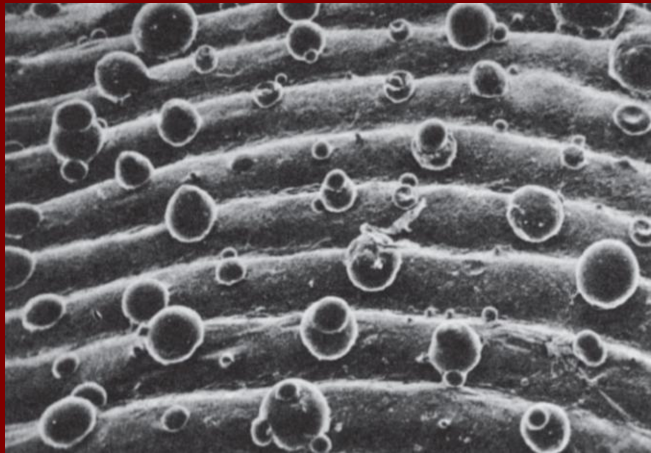
13

Touch



- Touch Physiology
- Tactile Sensitivity and Acuity
- Haptic Perception

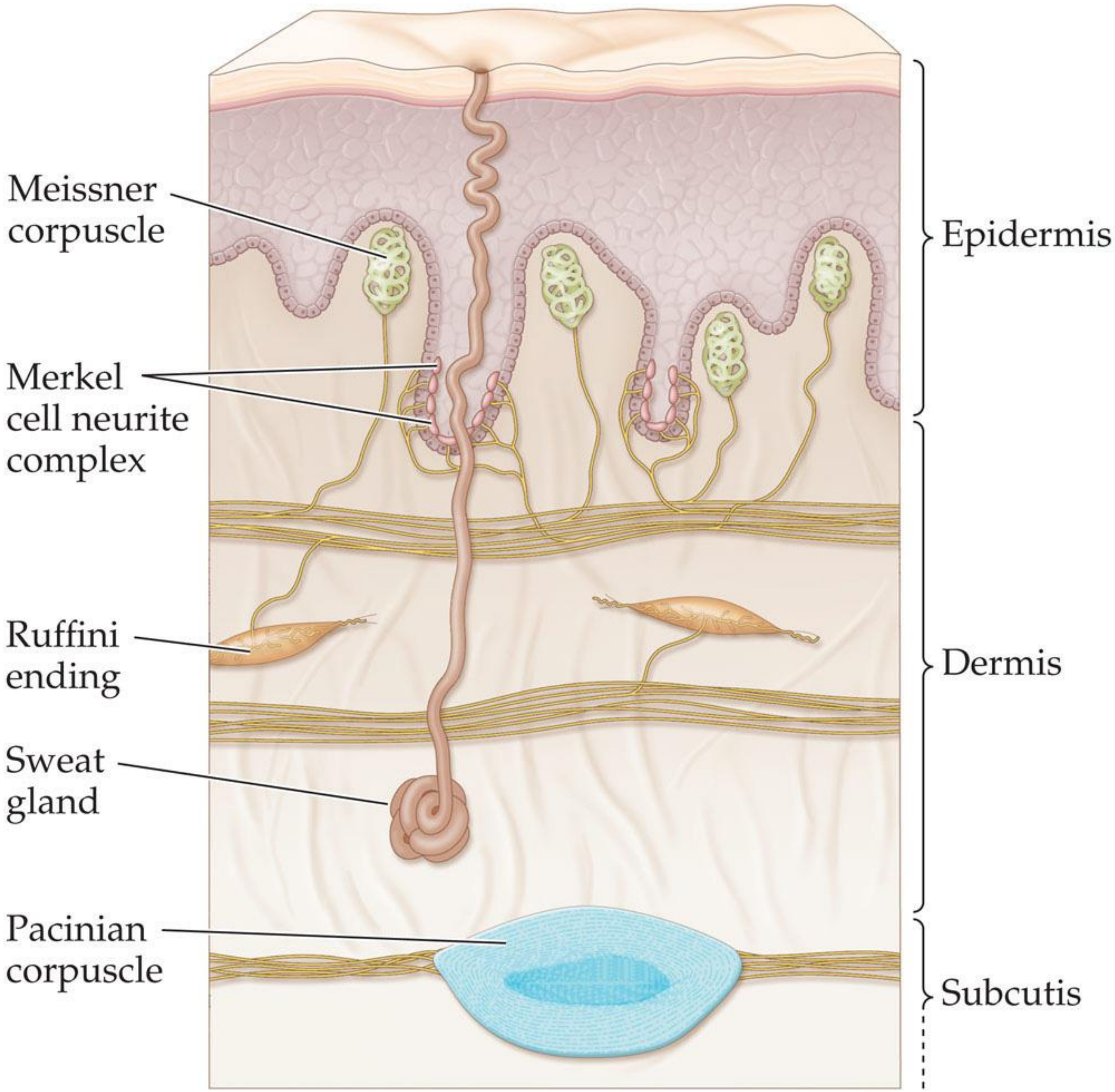
Some terminology:

- Kinesthesia: Perception of the position and movement of our limbs in space.
- Proprioception: Perception mediated by kinesthetic and internal receptors.
- Somatosensation: Collectively, sensory signals from the skin, muscles, tendons, joints, and internal receptors.

Touch receptors: Embedded in outer layer (epidermis) and underlying layer (dermis) of skin.

- Multiple types of touch receptors
- Each touch receptor can be categorized by three criteria:
  1. Type of stimulation to which the receptor responds
  2. Size of the receptive field
  3. Rate of adaptation (fast versus slow)

Figure 13.2 A cross section of hairless skin of the human hand, schematically demonstrating the locations of the four types of mechanoreceptors



SENSATION & PERCEPTION 4e, Figure 13.2

Touch Physiology

Tactile receptors

- Called “mechanoreceptors” because they respond to mechanical stimulation (pressure, vibration, or movement)
  - Meissner corpuscles—fast adaptation, small receptive field (FA I)
  - Merkel cell neurite complexes—slow adaptation, small receptive field (SA I)
  - Pacinian corpuscles—fast adaptation, large receptive field (FA II)
  - Ruffini endings—slow adaptation, large receptive field (SA II)

Tactile receptors (*continued*)

- Each receptor has a different range of responsiveness and functionality

TABLE 13.1

Response characteristics of the four mechanoreceptor populations

	Size of receptive field	
Adaptation rate	**Small**	**Large**
Slow	SA I (Merkel)	SA II (Ruffini)
Fast	FA I (Meissner)	FA II (Pacinian)

Note: FA I = fast-adapting type I; FA II = fast-adapting type II; SA I = slowly adapting type I; SA II = slowly adapting type II. The terminal ending associated with each type of tactile nerve fiber is shown in parentheses.

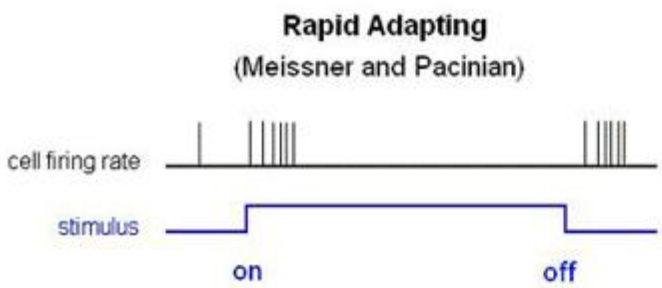
SENSATION & PERCEPTION 4e, Table 13.1

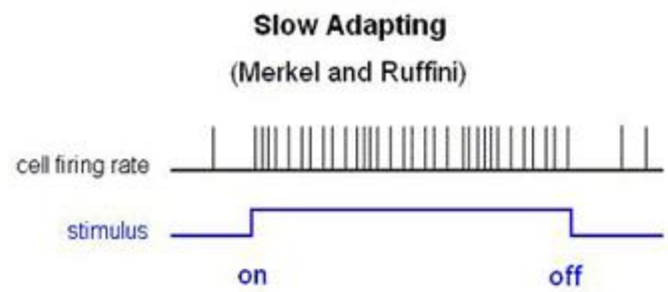
Table 13.2 Mechanoreceptors: Feature sensitivity and associated function

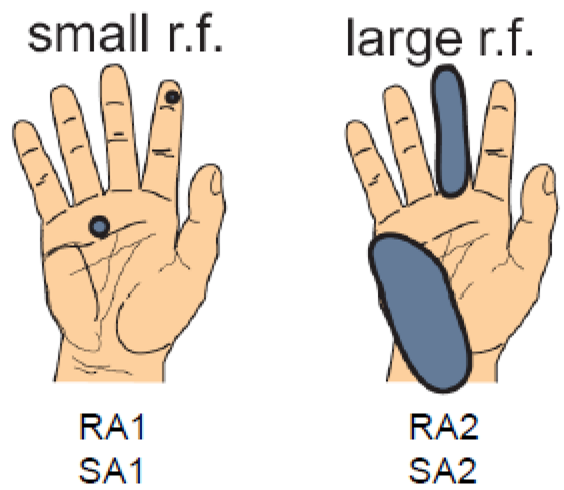
TABLE 13.2
Mechanoreceptors: Feature sensitivity and associated function

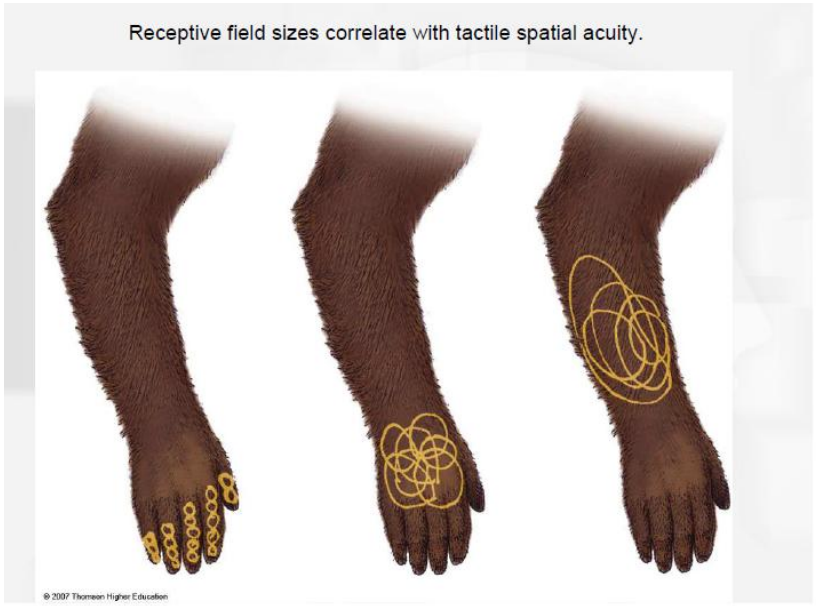
Mechanoreceptor population	Maximum feature sensitivity	Primary function(s)
SA I	Sustained pressure, very low frequency (< ~5 Hz) Spatial deformation	Texture perception Pattern/form perception
SA II	Sustained downward pressure (low sensitivity to vibration across frequencies) Lateral skin stretch	Finger position
FA I	Temporal changes in skin deformation (~5–50 Hz) Skin slip	Low-frequency vibration detection Stable grasp
FA II	Temporal changes in skin deformation (~50–700 Hz)	High-frequency vibration detection Fine texture perception

SENSATION & PERCEPTION 4e, Table 13.2


Rapid Adapting
(Meissner and Pacinian)
cell firing rate
stimulus
on
off


Slow Adapting
(Merkel and Ruffini)
cell firing rate
stimulus
on
off

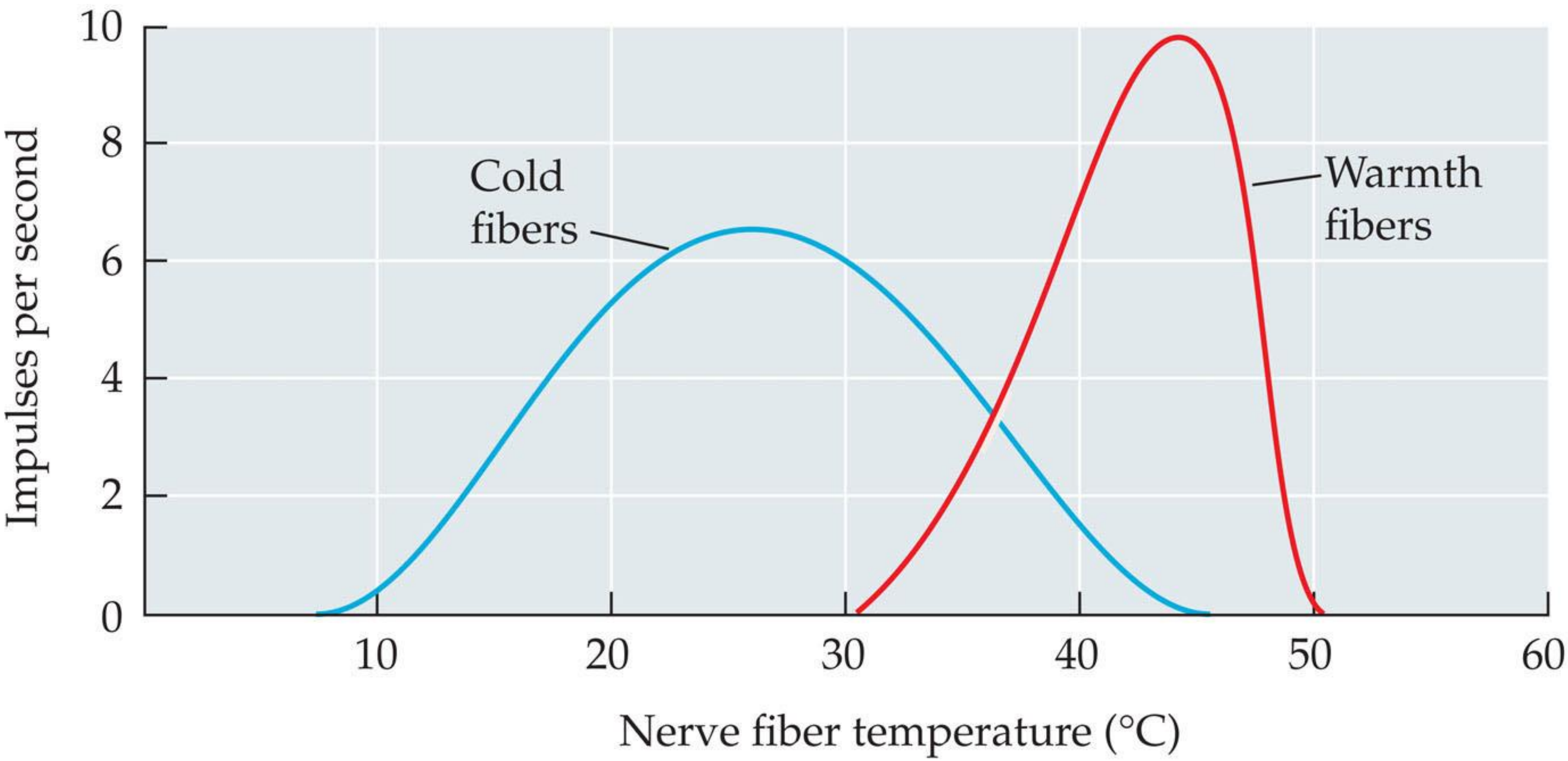

small r.f.
large r.f.
RA1
SA1
RA2
SA2


Receptive field sizes correlate with tactile spatial acuity.

Thermoreceptors

- Sensory receptors that signal information about changes in skin temperature
- Two distinct populations of thermoreceptors: warmth fibers, cold fibers
- Body is constantly regulating internal temperature
- Thermoreceptors respond when you make contact with an object warmer or colder than your skin

Figure 13.3 Thermal receptivity functions, showing the response of warmth and cold fibers to different temperatures



SENSATION & PERCEPTION 4e, Figure 13.3

Nociceptors

- Sensory receptors that transmit information about noxious stimulation that causes damage or potential damage to skin
- Two groups of nociceptors:
  - A-delta fibers: Intermediate-sized, myelinated sensory nerve fibers that transmit pain and temperature signals.
  - C fibers: Narrow-diameter, unmyelinated sensory nerve fibers that transmit pain and temperature signals.

Nociceptors (*continued*)

- Painful events have two stages—quick sharp pain (A-delta fibers) followed by throbbing sensation (C fibers).
  - Difference in speeds is due to myelination.

Benefit of pain perception

- Sensing dangerous objects
- Case of “Miss C”:
  - Born with insensitivity to pain
  - Did not sneeze, cough, gag, or blink reflexively
  - Suffered injuries such as burning herself on radiator and biting tongue while chewing food
  - Died at age 29 from infections that could have been prevented if she sensed pain

Pleasant touch

- Classic categories of discriminative touch: tactile, thermal, pain, and itch
- Newly uncovered fifth component of touch: pleasant touch
  - Mediated by unmyelinated peripheral C fibers known as “C tactile afferents” (CT afferents)
  - CT afferents not related to pain or itch

Pleasant touch (*continued*)

- Respond best to slowly moving, lightly applied forces (e.g., petting)
- Processed in orbitofrontal cortex rather than S1 or S2

Touch Physiology

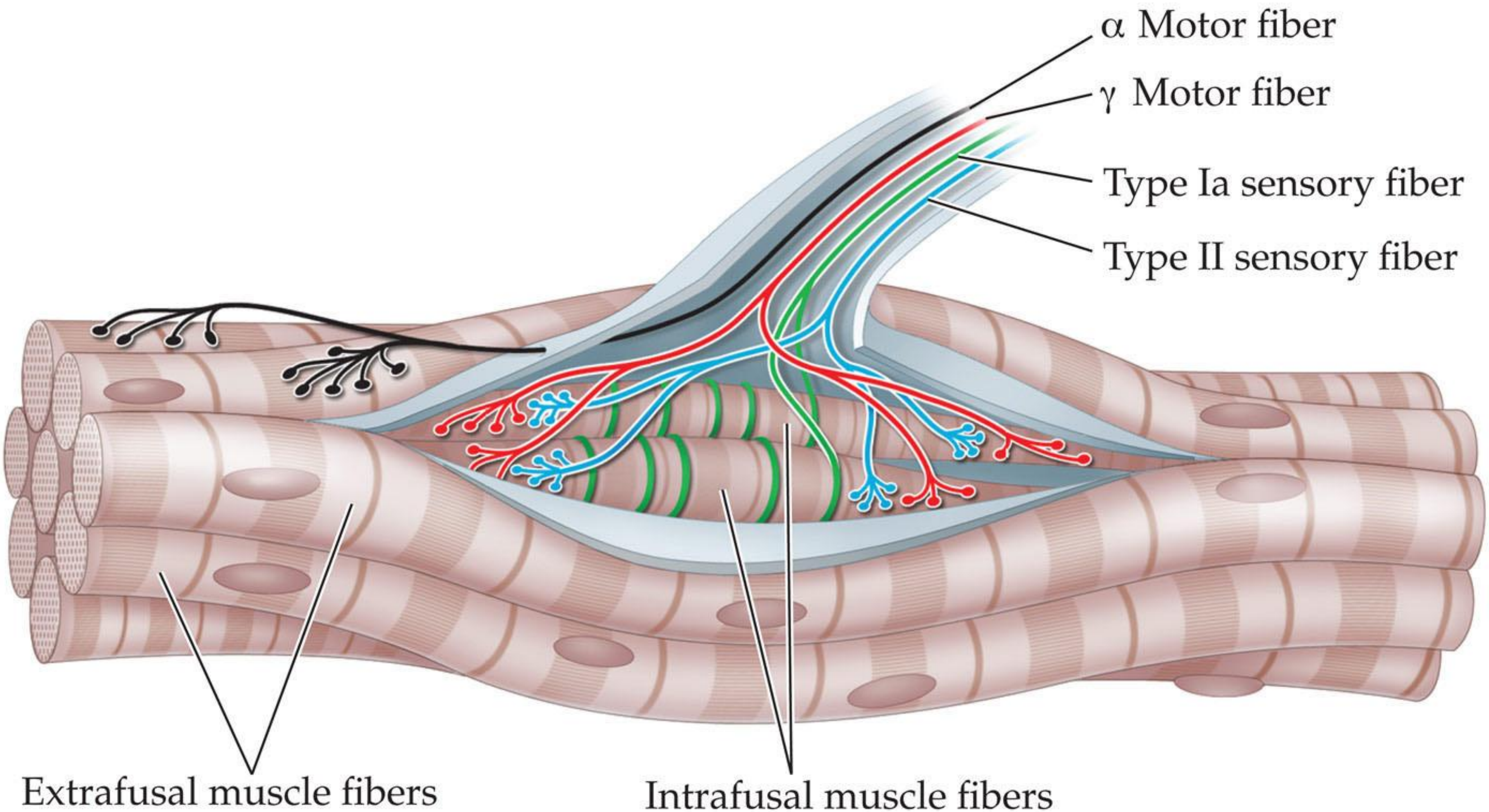
Other types of mechanoreceptors within muscles, tendons, and joints

- Kinesthetic receptors: Mechanoreceptors in muscles, tendons, and joints.
  - Play an important role in sense of where limbs are, what kinds of movements are made

Touch Physiology

- Muscle spindle: A sensory receptor located in a muscle that senses its tension.
  - Receptors in tendons signal tension in muscles attached to tendons
  - Receptors in joints react when joint is bent to an extreme angle

Figure 13.4 A muscle spindle embedded in main (extrafusal) muscle fibers contains inner (intrafusal) fibers



SENSATION & PERCEPTION 4e, Figure 13.4

Importance of kinesthetic receptors

- Strange case of neurological patient Ian Waterman:
  - Cutaneous nerves connecting Waterman’s kinesthetic mechanoreceptors to brain destroyed by viral infection
  - Lacks kinesthetic senses, dependent on vision to tell limb positions

Touch sensations travel as far as 2 meters to get from skin and muscles of feet to brain!

- Information must pass through spinal cord
- Axons of various tactile receptors combine into single nerve trunks
  - Labeled lines: Each fiber type from the skin codes a particular touch sensation.
  - Labeled lines become interconnected in spinal cord, allowing complex patterns to emerge.

Touch Physiology

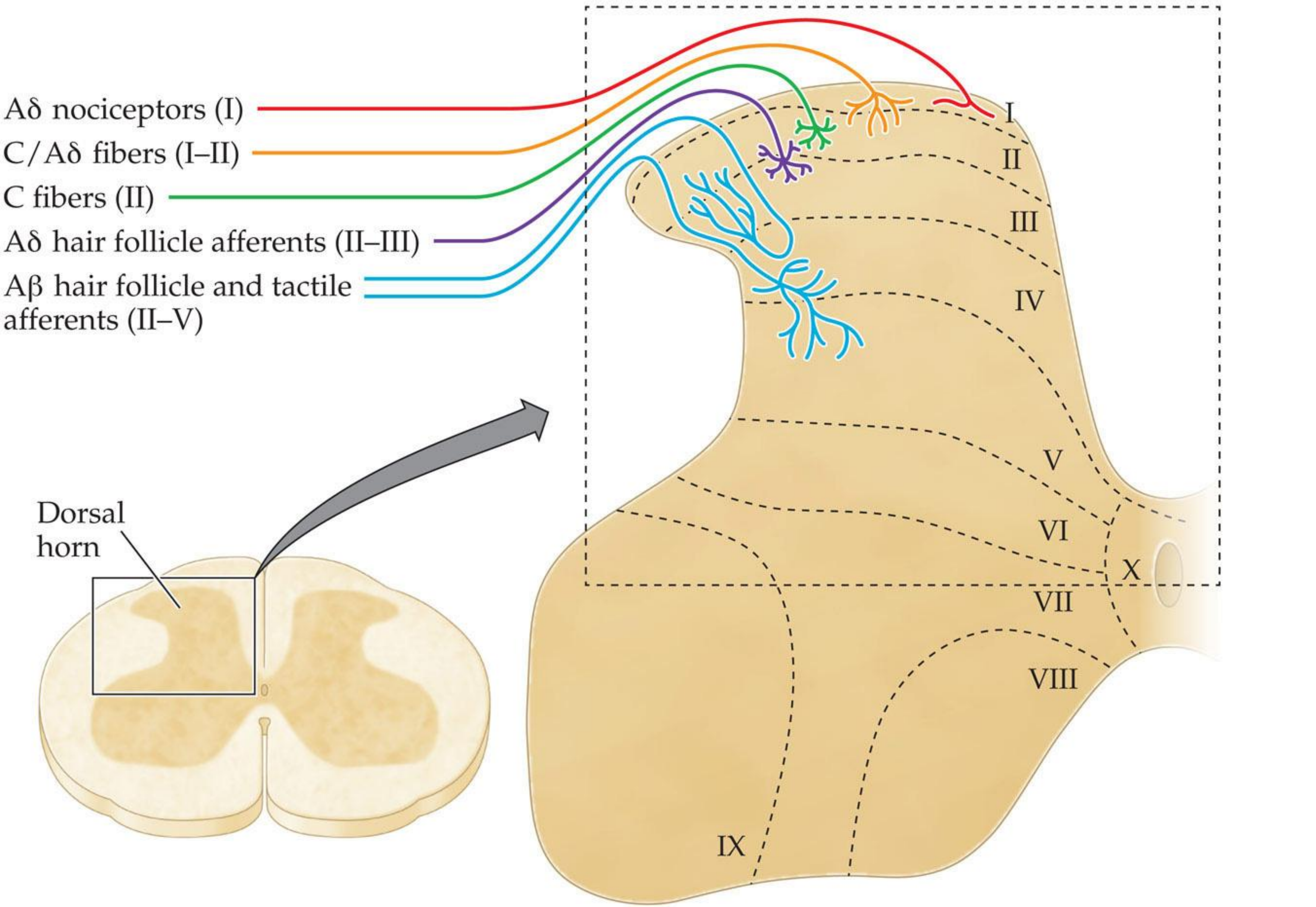
Axons from touch fibers enter the spinal cord in the dorsal horn.

- Dorsal horn is organized into multiple layers, or laminae.
- Every skin mechanoreceptor projects into the dorsal horn.

Touch Physiology

- Inputs to spinal cord organized somatotypically—adjacent areas of the skin project to adjacent areas in the spinal cord.
- Complex calculations that enrich touch sensations occur in the dorsal horn.

Figure 13.5 Neural projections to the dorsal horn of the spinal cord, based on the cat, rat, and monkey



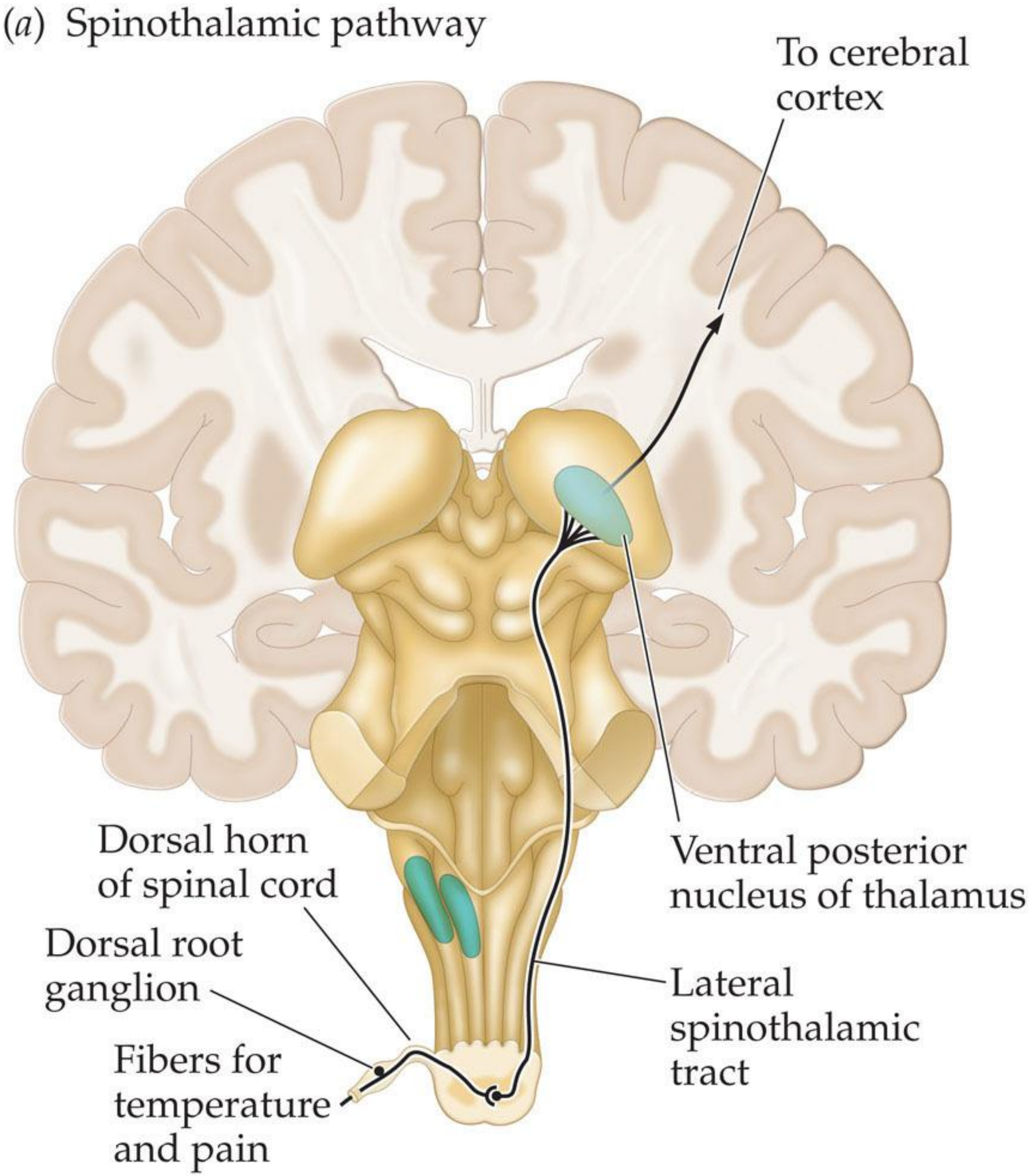
SENSATION & PERCEPTION 4e, Figure 13.5

Touch Physiology

Two major pathways from spinal cord to brain

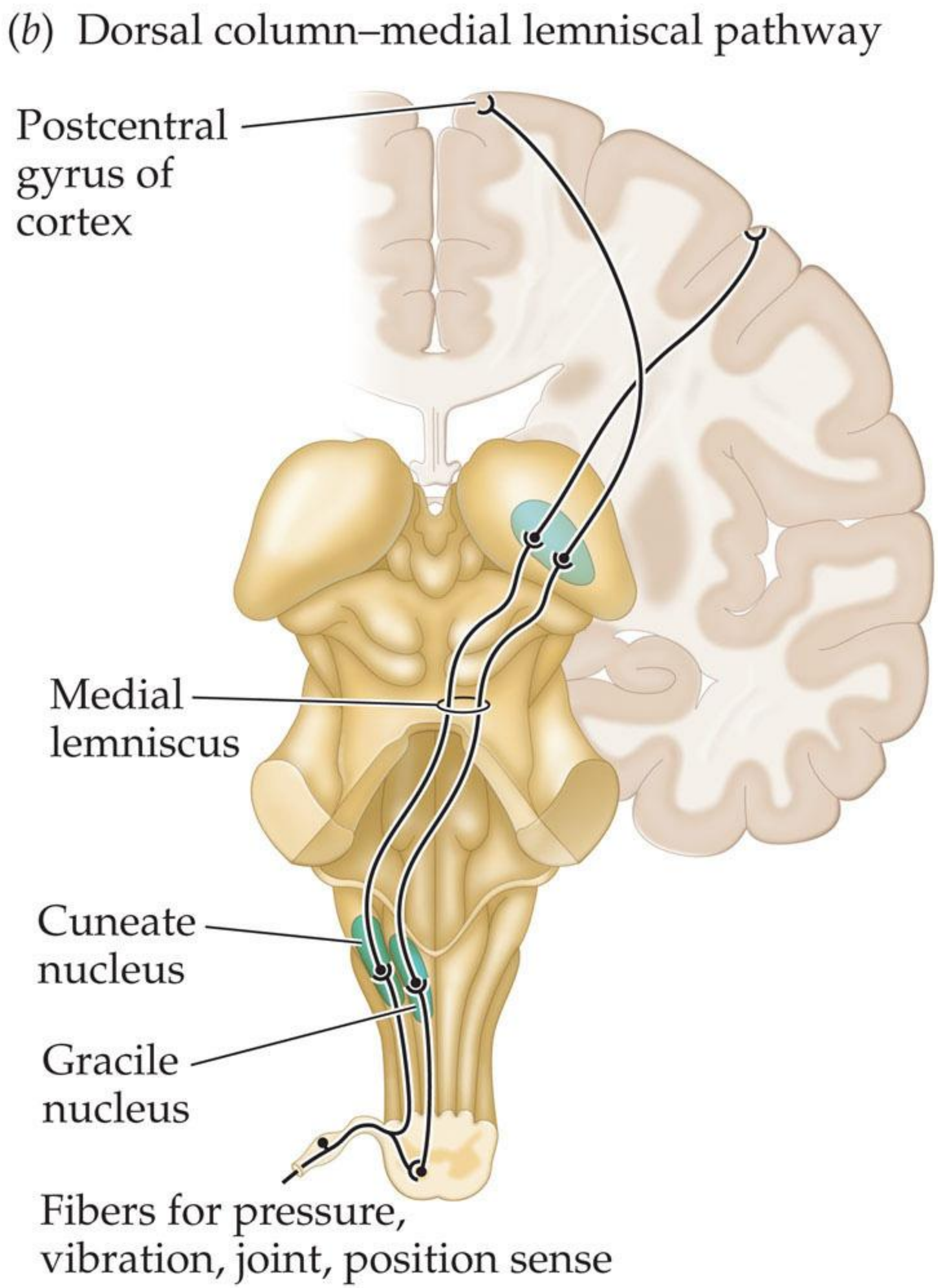
- Spinothalamic pathway: Carries most of the information about skin temperature and pain (slower).
- Dorsal column-medial lemniscal (DCML) pathway: Carries signals from skin, muscles, tendons, and joints.

Figure 13.6 Pathways from skin to cortex (Part 1)



SENSATION & PERCEPTION 4e, Figure 13.6 (Part 1)

Figure 13.6 Pathways from skin to cortex (Part 2)



SENSATION & PERCEPTION 4e, Figure 13.6 (Part 2)

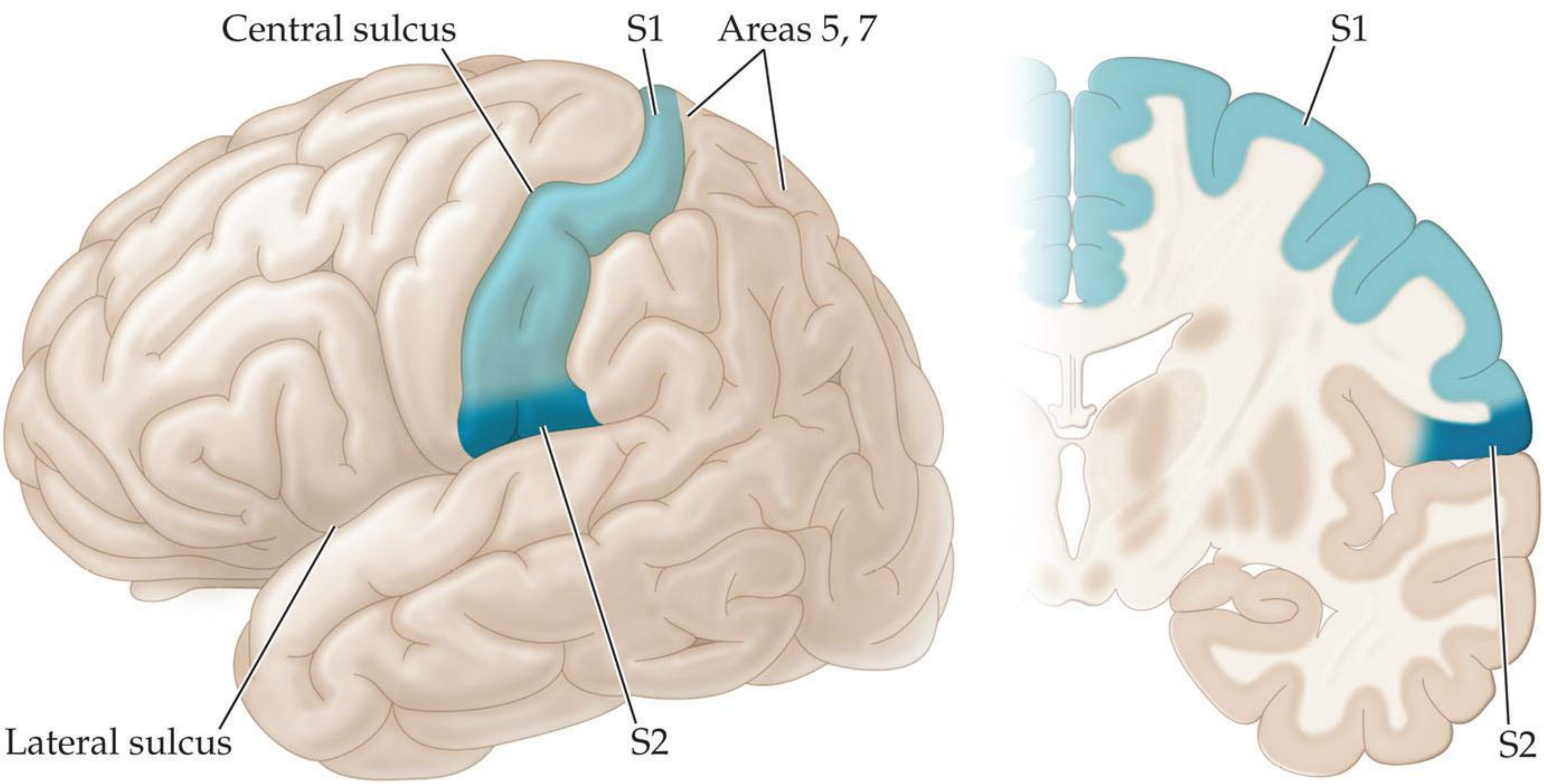
Touch Physiology

Touch sensations are represented somatotopically in the brain.

- Primary somatosensory cortex called S1; secondary somatosensory cortex called S2
- Analogous to retinotopic mapping found in vision

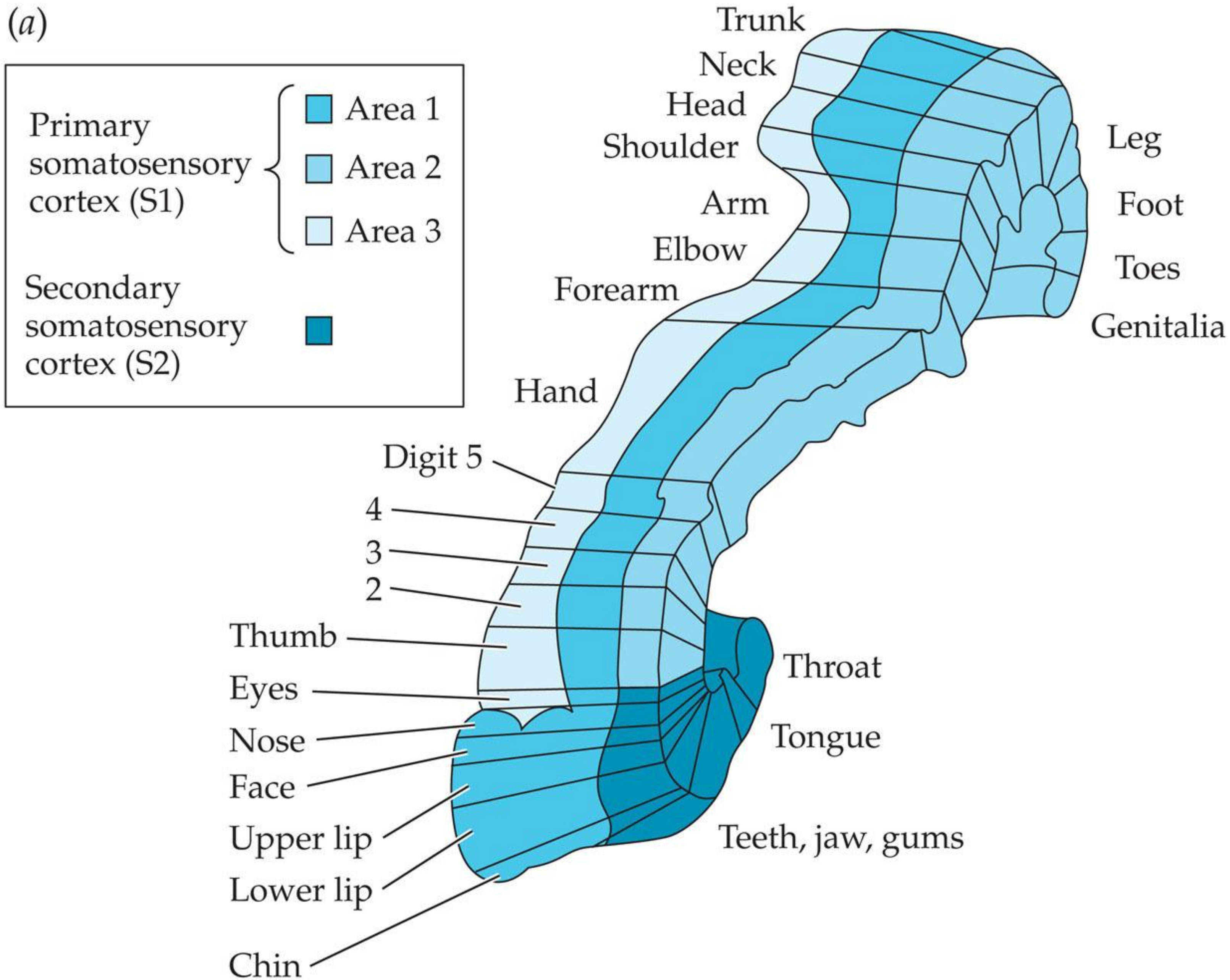
- Adjacent areas on skin connect to adjacent areas in brain.
  - Homunculus: Maplike representation of regions of the body in the brain.
- Brain contains several sensory maps of body in different areas of S1 and also in S2.

Figure 13.7 Primary somatosensory receiving areas in the brain



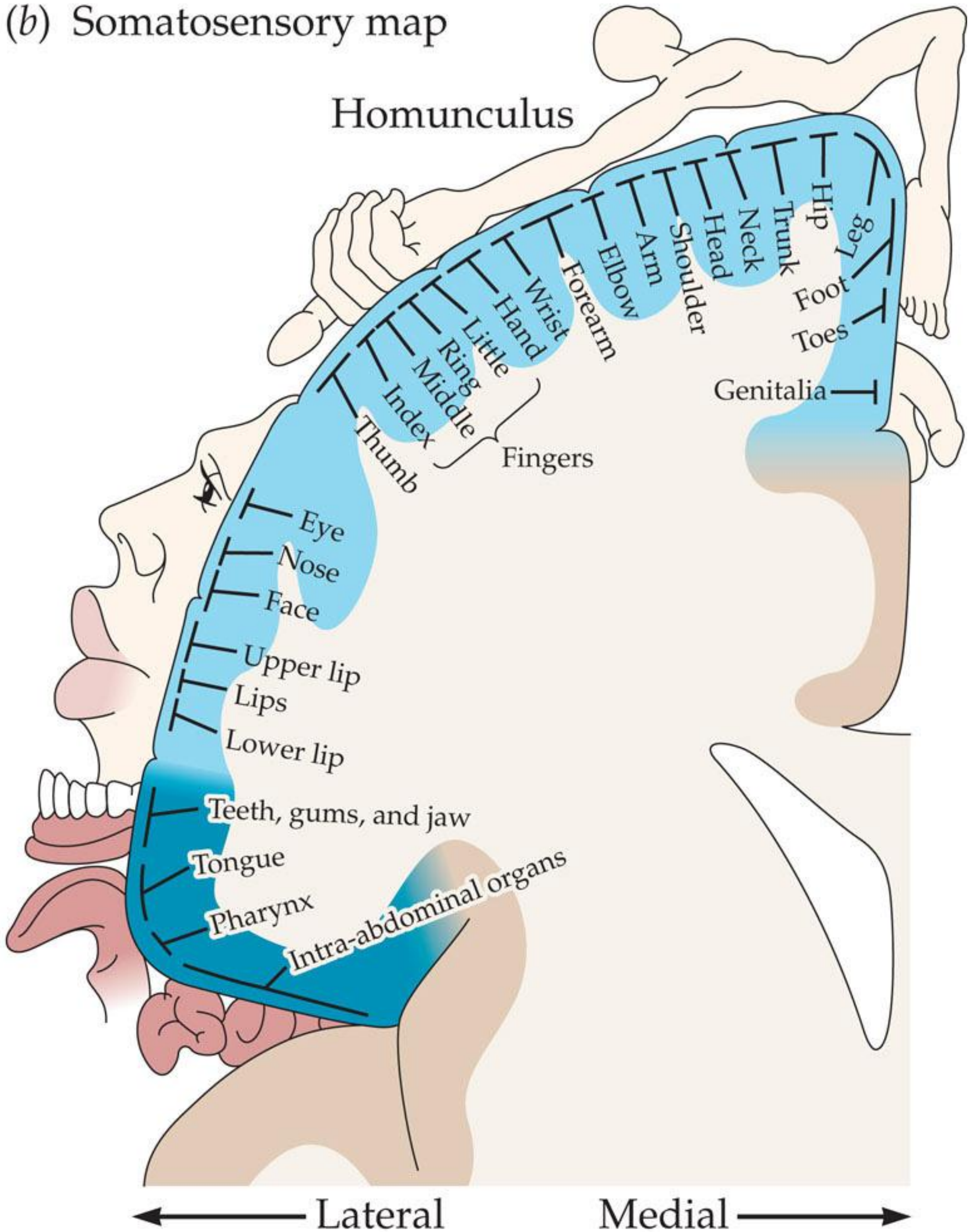
SENSATION & PERCEPTION 4e, Figure 13.7

Figure 13.8 The sensory homunculus (Part 1)



SENSATION & PERCEPTION 4e, Figure 13.8 (Part 1)

Figure 13.8 The sensory homunculus (Part 2)



SENSATION & PERCEPTION 4e, **Figure 13.8 (Part 2)**

Body image: The impression of our bodies in space.

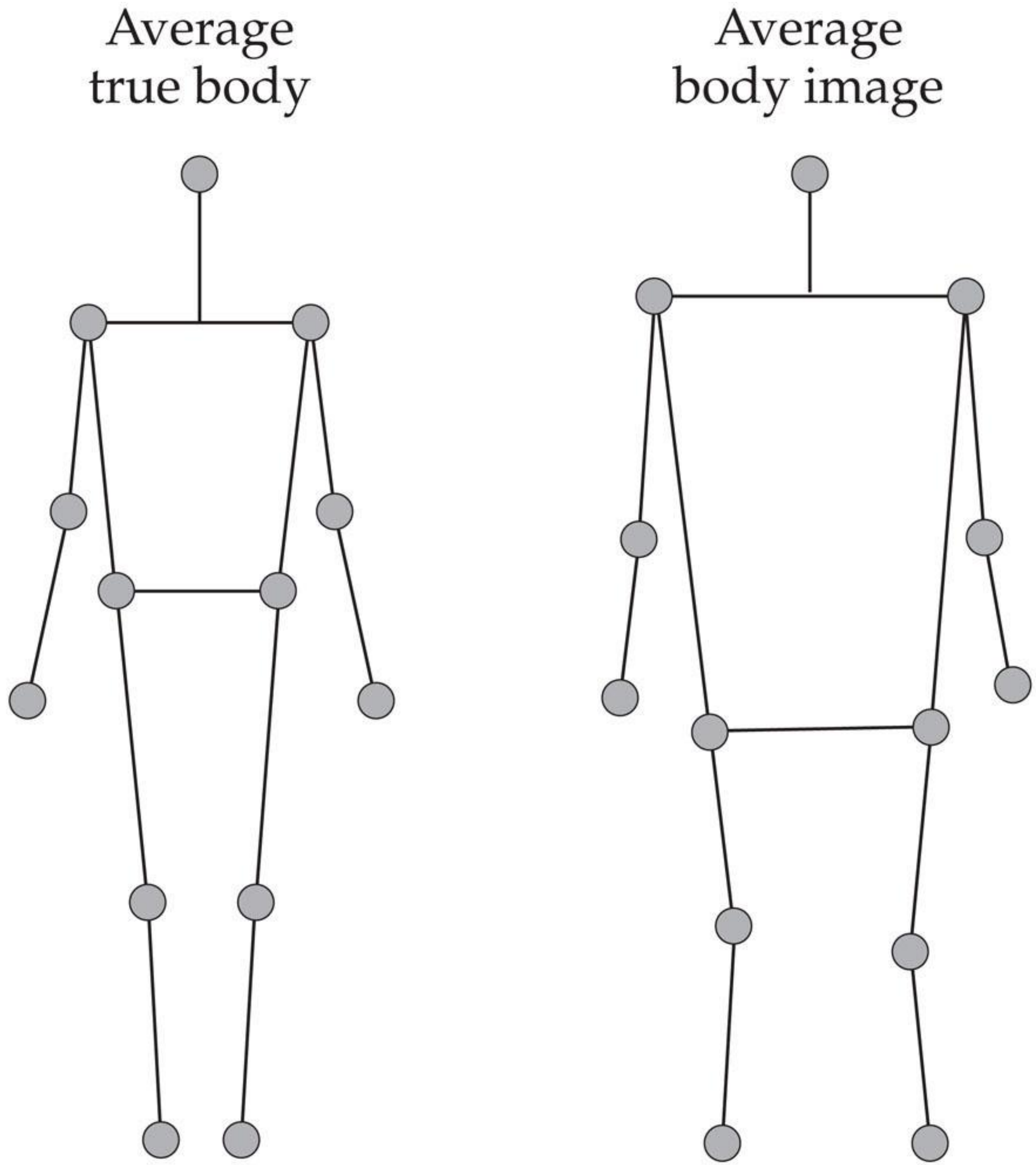
Our body images are systematically distorted towards top-heaviness.

- Expanded shoulders and upper arms
- People rate upper half of body to be larger than lower half.
- Consistent with somatotopic mapping in cortex and sensory homunculus

Touch Physiology

People who have surgery to increase the length of their arms (shortened due to dwarfism) have updated body images to reflect longer arms within 6 months.

Figure 13.9 Shape of the body as determined from locations of parts for people's true body and locations they report relative to the head, which form their body image



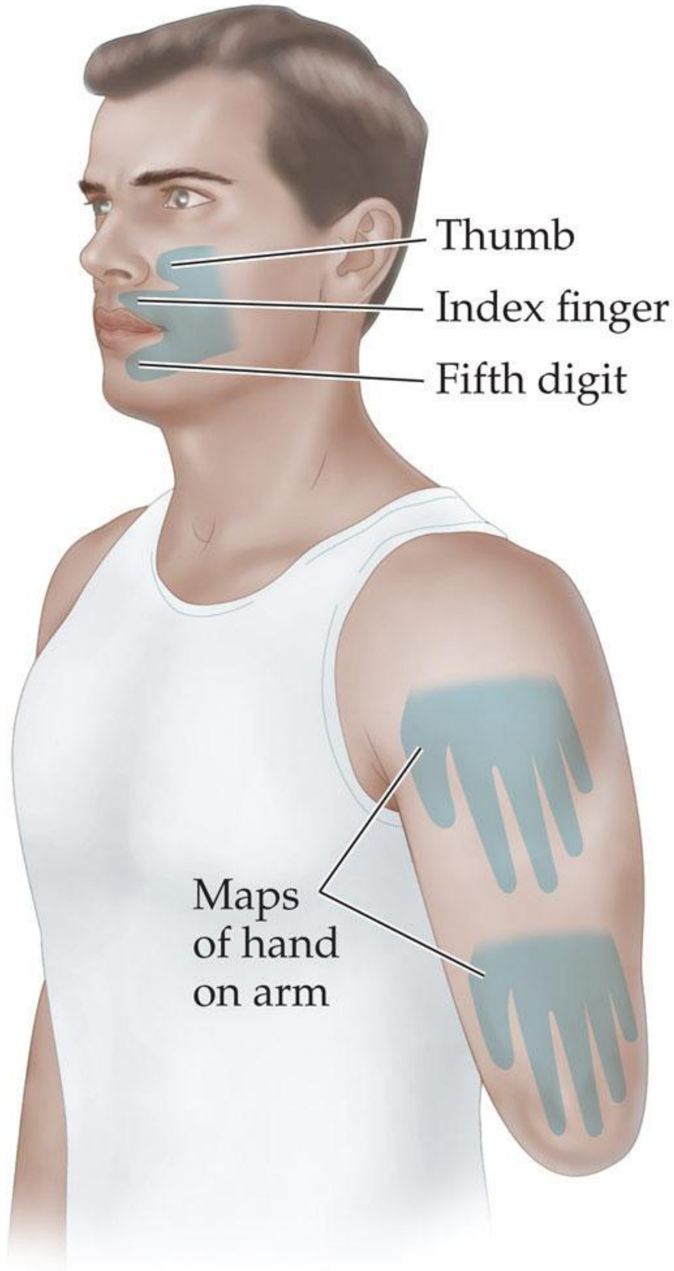
SENSATION & PERCEPTION 4e, Figure 13.9

Phantom limb: Sensation perceived from a physically amputated limb of the body.

- Parts of brain listening to missing limbs not fully aware of altered connections, so they attribute activity in these areas to stimulation from missing limb.
  - Body image is inaccurate.

- Amputees report feeling the amputated hand when their face or remaining limbs are stimulated.
  - Face area is located next to hand and arm area on sensory homunculus. Neural crosstalk leads to sensory crosstalk.

Figure 13.10 Phantom limbs may be perceived on the face and stump subsequent to amputation



SENSATION & PERCEPTION 4e, Figure 13.10

Neural plasticity: The ability of neural circuits to undergo changes in function or organization as a result of previous activity.

- Pascual-Leone & Hamilton (2001) blindfolded participants for 5 days.
- Tested their sensitivity to braille stimulation on their right index finger each day, scanned their brains using fMRI.

Touch Physiology

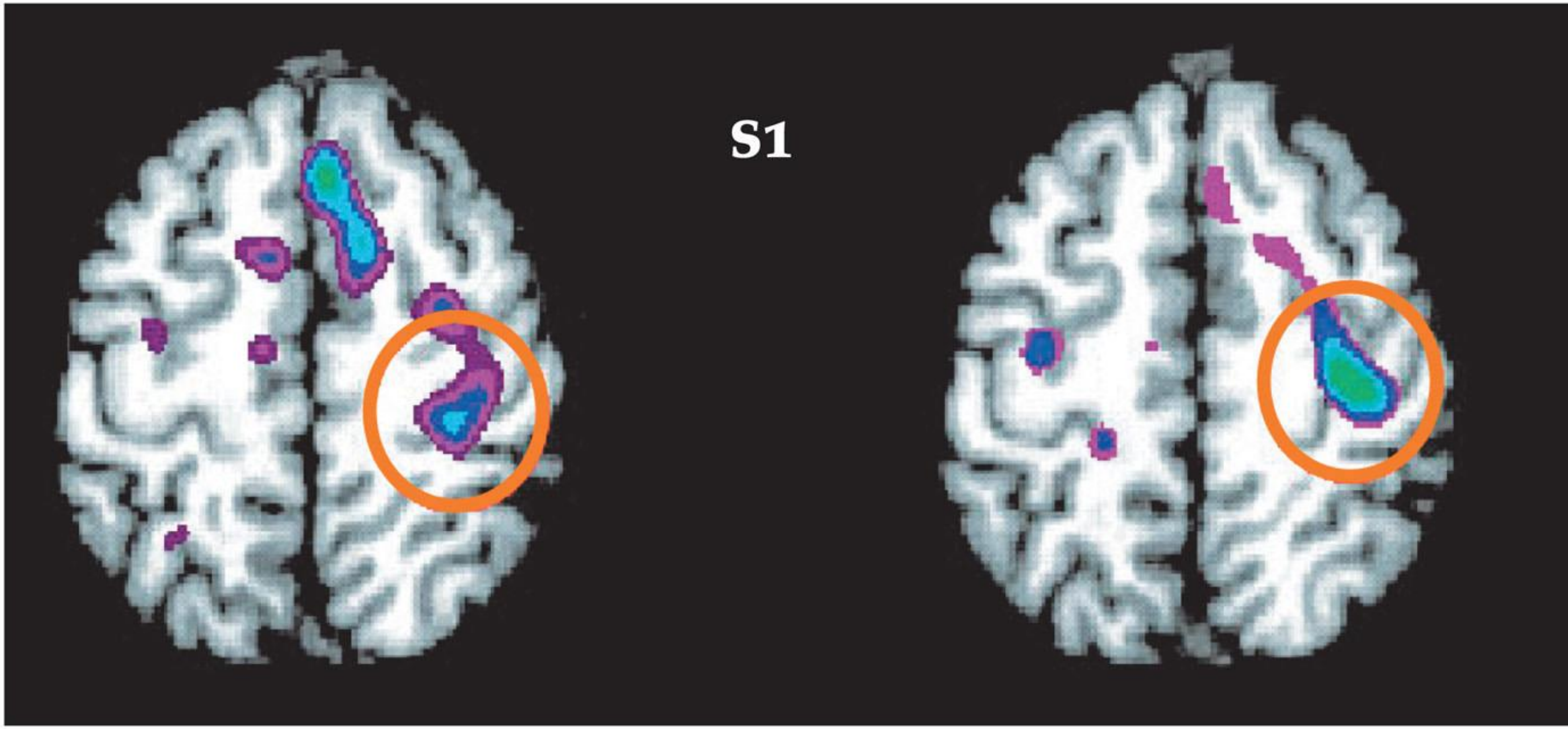
- First day, only area S1 in left hemisphere activated.
- By fifth day, S1 activation had decreased and V1 activation increased!
  - V1 switched over from vision to analyzing touch sensations.
- Once blindfolds removed, neural functioning changed back to normal.

Pain

- Pain sensations triggered by nociceptors
- Responses to noxious stimuli can be moderated by anticipation, religious belief, prior experience, watching others respond, and excitement.
  - Example: Wounded soldier in battle who does not feel pain until after battle

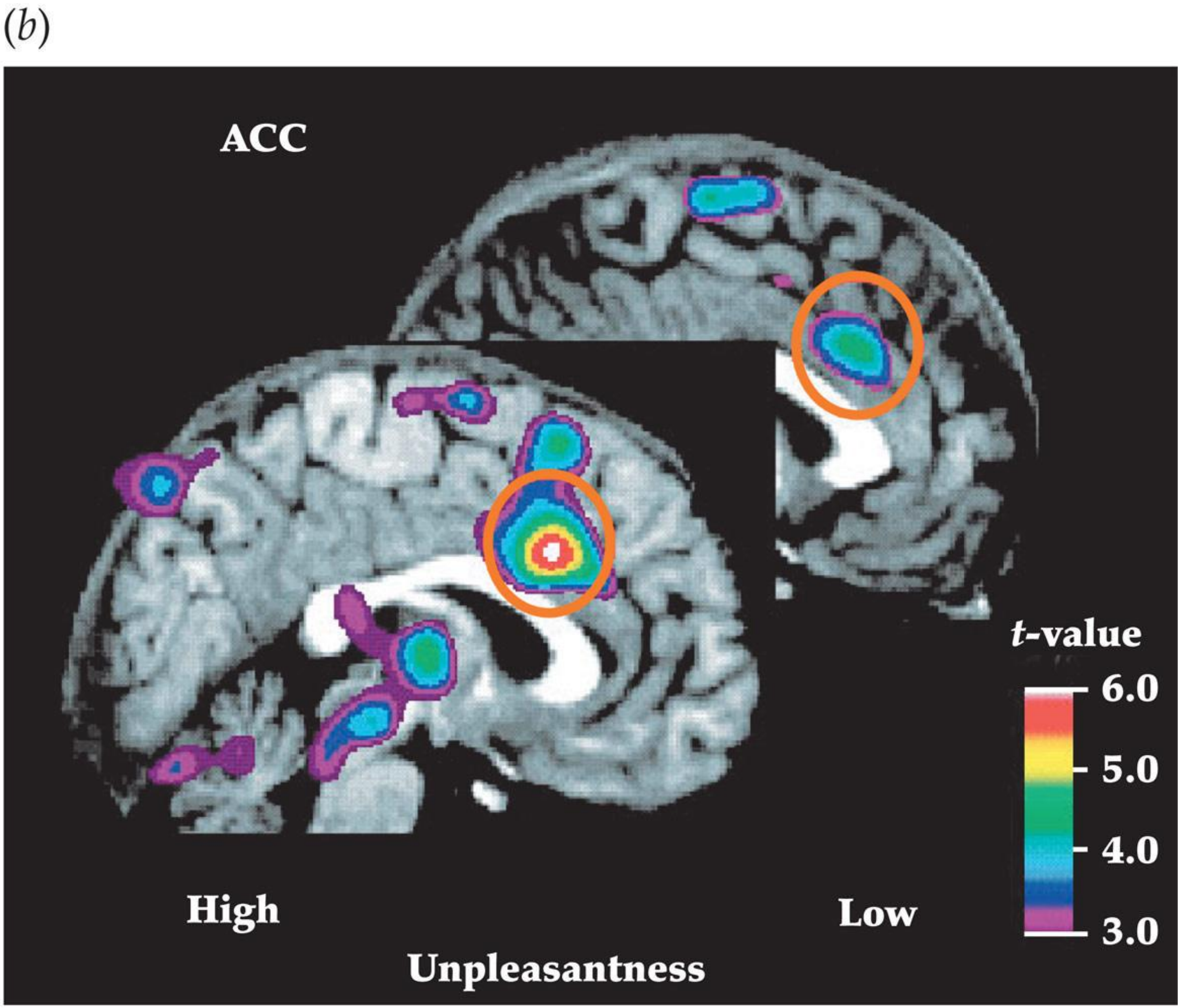
Figure 13.11 PET signals showing effects of hypnosis on the brain, as observed by Rainville et al. (Part 1)

(*a*)



SENSATION & PERCEPTION 4e, Figure 13.11 (Part 1)

Figure 13.11 PET signals showing effects of hypnosis on the brain, as observed by Rainville et al. (Part 2)



SENSATION & PERCEPTION 4e, Figure 13.11 (Part 2)

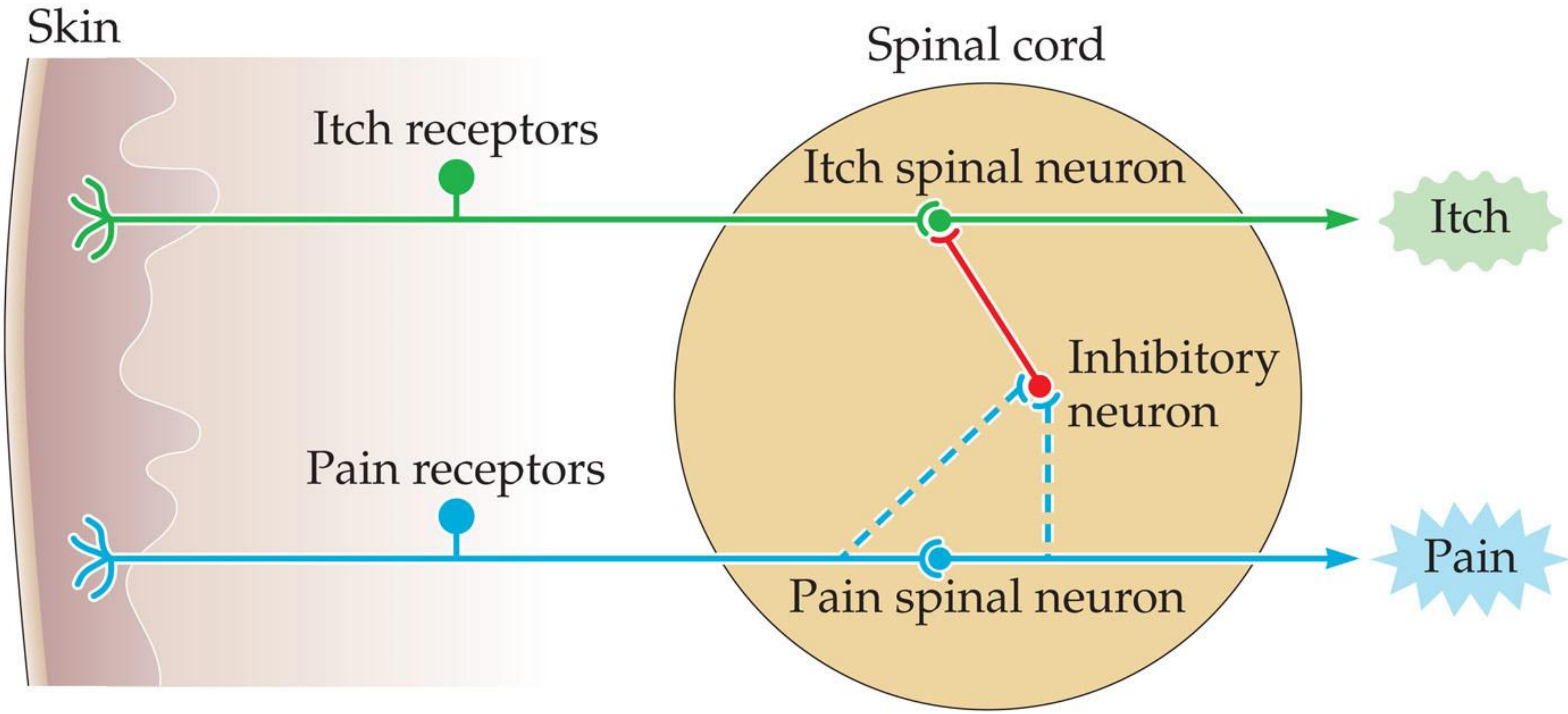
Analgesia: Decreasing pain sensation during conscious experience.

- Soldier in above example: Experienced effect because of endogenous opiates—chemicals released in body to block release or uptake of neurotransmitters transmitting pain sensation to brain
  - Endogenous opiates may be responsible for certain placebo effects.
- Externally produced substances have similar effect: morphine, heroin, codeine

Gate control theory

- A description of the system that transmits pain that incorporates modulating signals from the brain
- Gate neurons that block pain transmission can be activated by extreme pressure, cold, or other noxious stimulation applied to another site distant from the source of pain.

Figure 13.12 Pain and itch stimulation are initially transmitted by separate “labeled lines”



SENSATION & PERCEPTION 4e, Figure 13.12

Cognitive aspects of pain

- Pain is generally a subjective experience with two components: sensation of the painful stimulus and the emotional response to it.
- Areas S1 and S2 are responsible for sensory aspects of pain.

Cognitive aspects of pain (*continued*)

- Recently, researchers have identified areas of brain that correspond to more cognitive aspects of painful experiences.
  - Anterior cingulate: A region of the brain associated with the perceived unpleasantness of pain sensations.
  - Prefrontal cortex: A region of the brain concerned with cognition and executive control. May contribute to pain sensitization.

Pain sensitization

- Nociceptors provide signal when there is impending or ongoing damage to body's tissue—"nociceptive" pain
- Once damage has occurred, site can become more sensitive—hyperalgesia
- Pain as a result of damage to or dysfunction of nervous system—neuropathic
- No single pain medication will alleviate all types of pain.

Tactile Sensitivity and Acuity

How sensitive are we to mechanical pressure?

- Max von Frey (1852–1932) developed an elegant way to measure tactile sensitivity.
  - Used horse and human hairs
  - Modern researchers use nylon monofilaments of varying diameters

Tactile Sensitivity and Acuity

Hairs or monofilaments of varying diameters are pressed against the skin to see if the pressure can be sensed.

- The smaller the diameter of the monofilament, the less force applied to the skin before it buckles.

Tactile Sensitivity and Acuity

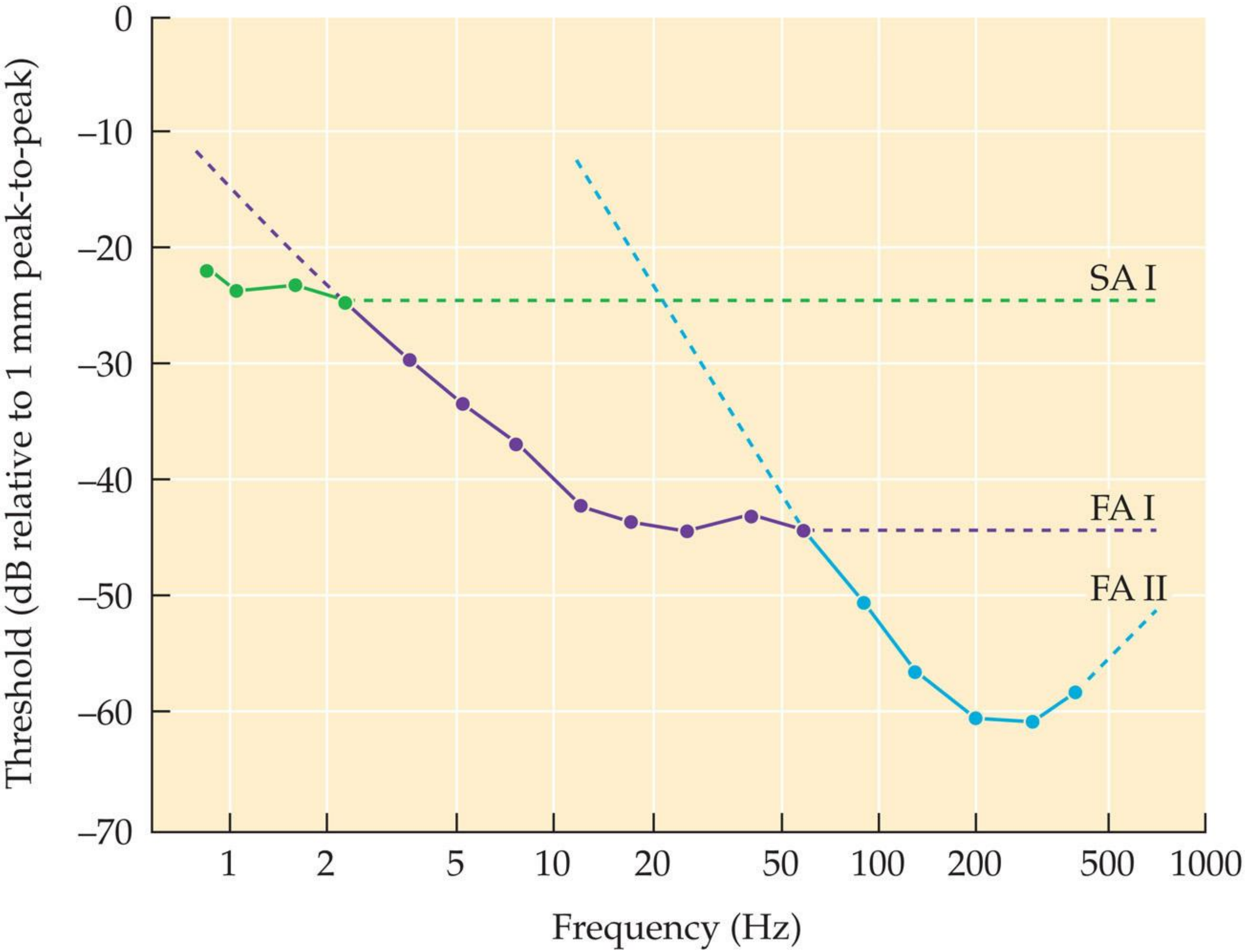
- Sensitivity to mechanical pressure varies over the body.
  - Face is most sensitive
  - Trunk and upper extremities (arms and fingers) next most sensitive
  - Lower extremities (thigh, calf, and foot) less sensitive

Tactile Sensitivity and Acuity

Another approach to tactile sensitivity: What is the smallest raised element that can be felt on an otherwise smooth surface?

- People can detect a bump only 10 nanometers high!
- Dot triggers FA I receptors, which also help detect slippage of objects while being grasped
- Surface with many dots a fraction of a micrometer high can be detected when moved across the skin via FA II receptors deep in skin

Figure 13.13 Results of an experiment measuring the minimal (threshold) amplitude of vibration at the fingertip that people can detect, as a function of the vibratory frequency

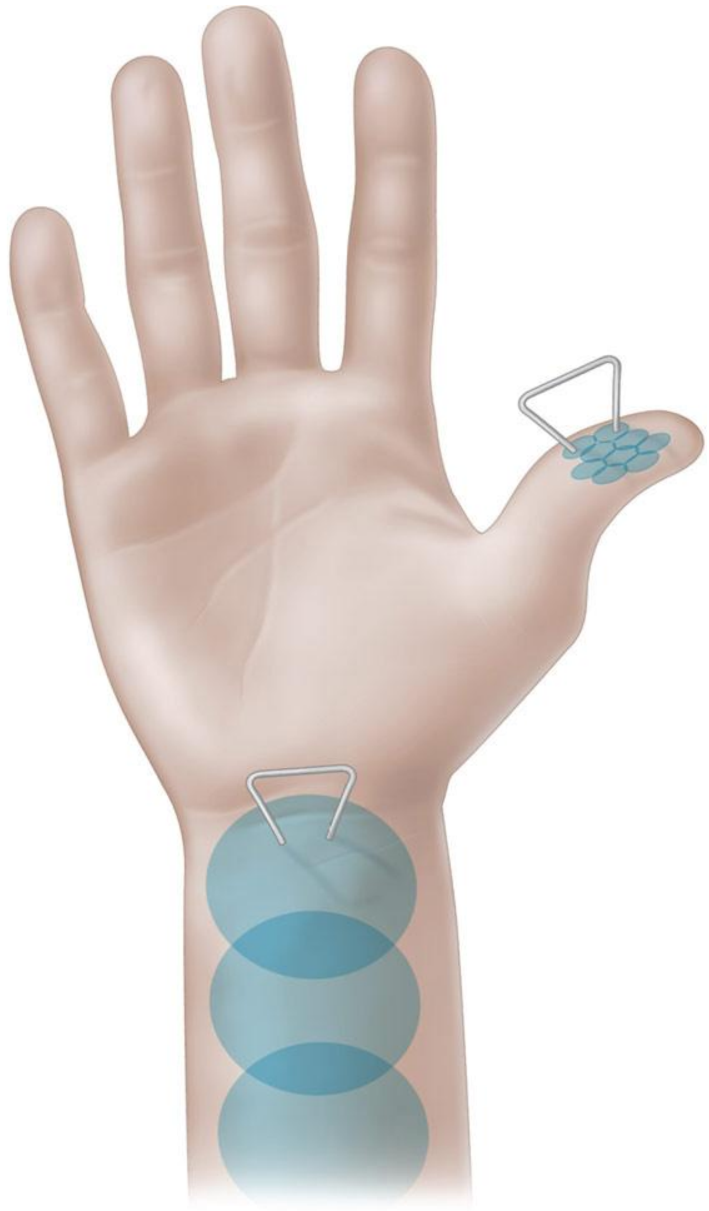


Tactile Sensitivity and Acuity

How finely can we resolve spatial details?

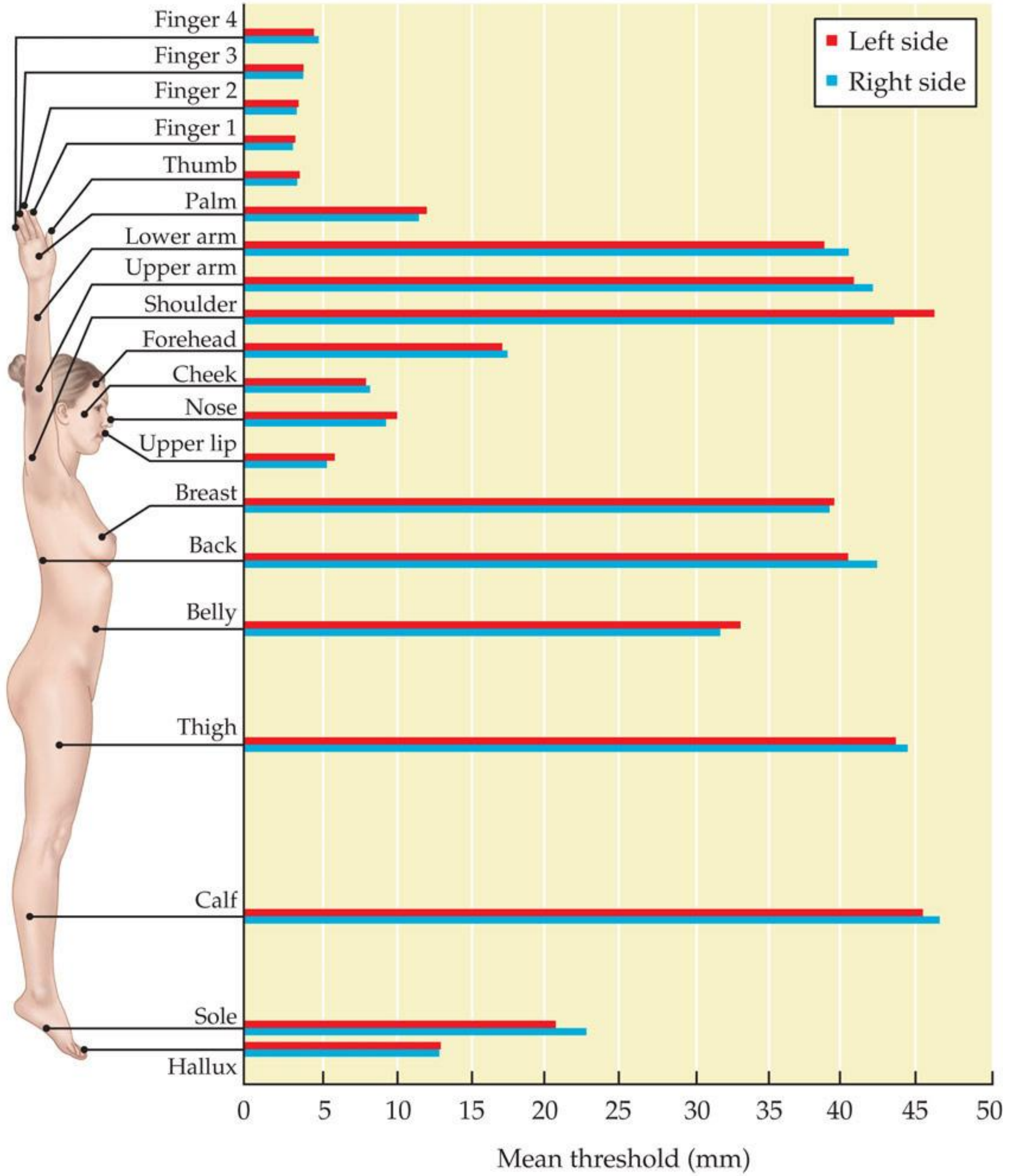
- Two-point threshold: The minimum distance at which two stimuli are just perceptible as separate.
- Like sensitivity to pressure, spatial acuity varies across the body.
  - Extremities (fingertips, face, and toes) show the highest acuity.

Figure 13.14 Two-point touch thresholds are determined primarily by the concentration and receptive-field sizes of tactile receptors in an area of the skin



SENSATION & PERCEPTION 4e, Figure 13.14

Figure 13.15 The two-point touch threshold when the points are applied at different sites on the body



SENSATION & PERCEPTION 4e, **Figure 13.15**

Tactile Sensitivity and Acuity

How finely can we resolve temporal details?

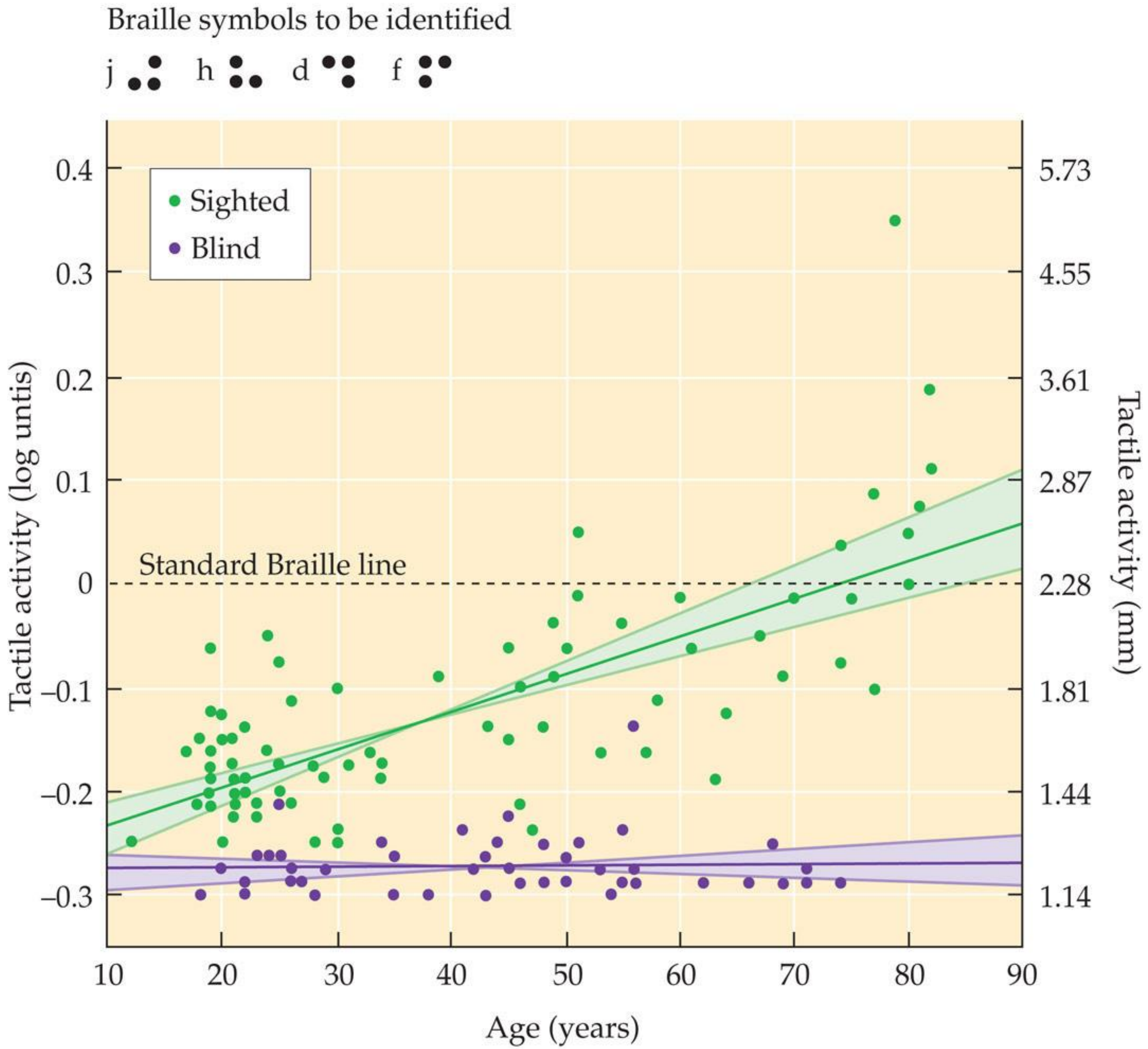
- Two tactile pulses can be delivered over time, in a manner analogous to spatially separated two-point threshold stimuli.
- Touch—sensitive to time differences of only 5 ms
- Vision—sensitive to time differences of 25 ms
- Audition—sensitive to time differences of 0.01 ms!

Tactile Sensitivity and Acuity

Do people differ in tactile sensitivity?

- For sighted people, tactile sensitivity declines with age.
- For blind people, tactile sensitivity remains high into older age.
- Sadly, this implies that people who lose sight later in life may not be able to read Braille because their sensitivity has declined too much.

Figure 13.16 Tactile acuity versus age



SENSATION & PERCEPTION 4e, Figure 13.16

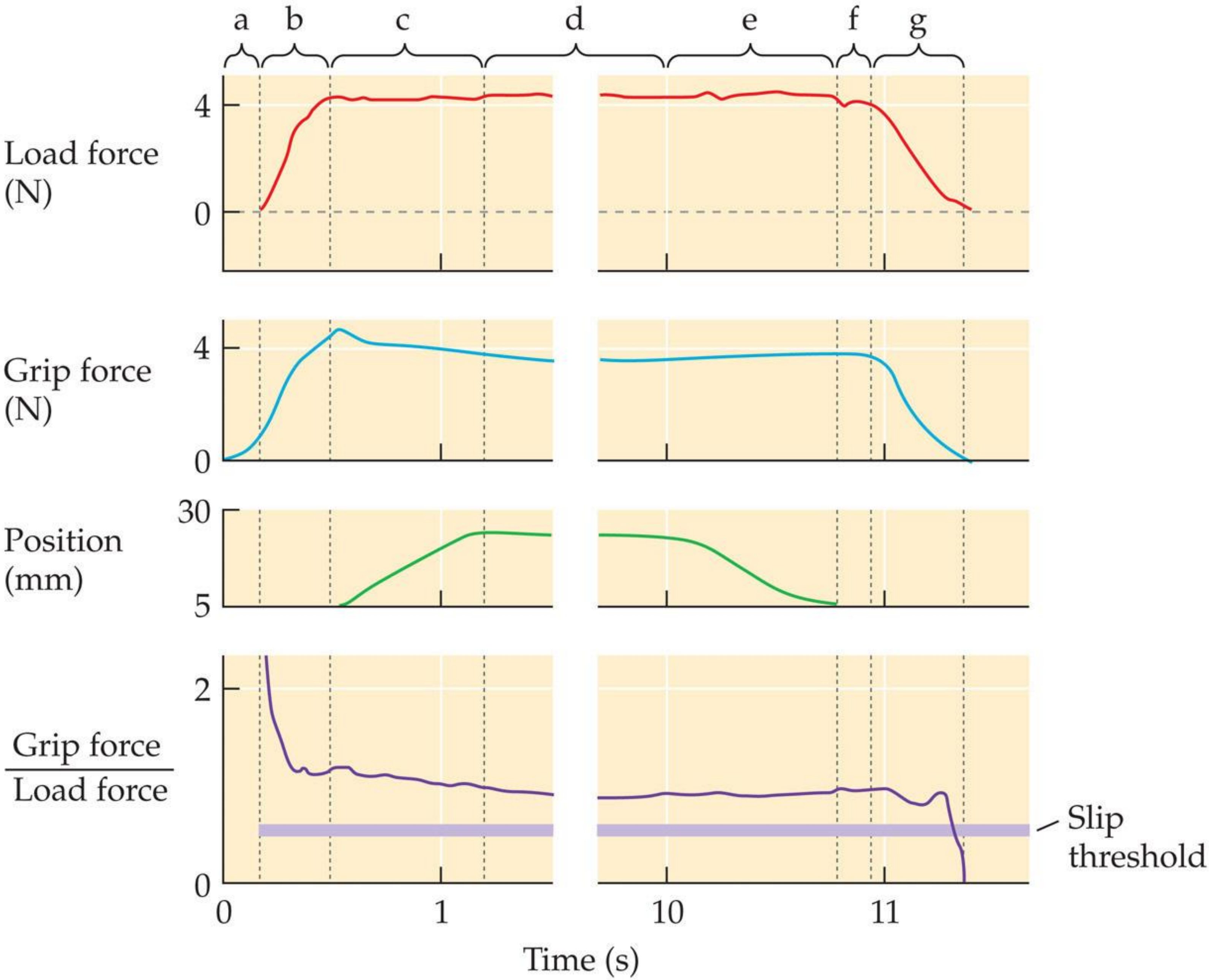
Haptic perception

- Knowledge of the world that is derived from sensory receptors in skin, muscles, tendons, and joints, usually involving active exploration
  - For instance, aligning the arrows and opening a child-proof aspirin bottle in the dark

Perception for action

- Using somatosensation to grasp and manipulate objects in a stable and coordinated manner and to maintain proper posture and balance

Figure 13.17 Force and position during lifting, grasping, and replacing a cube

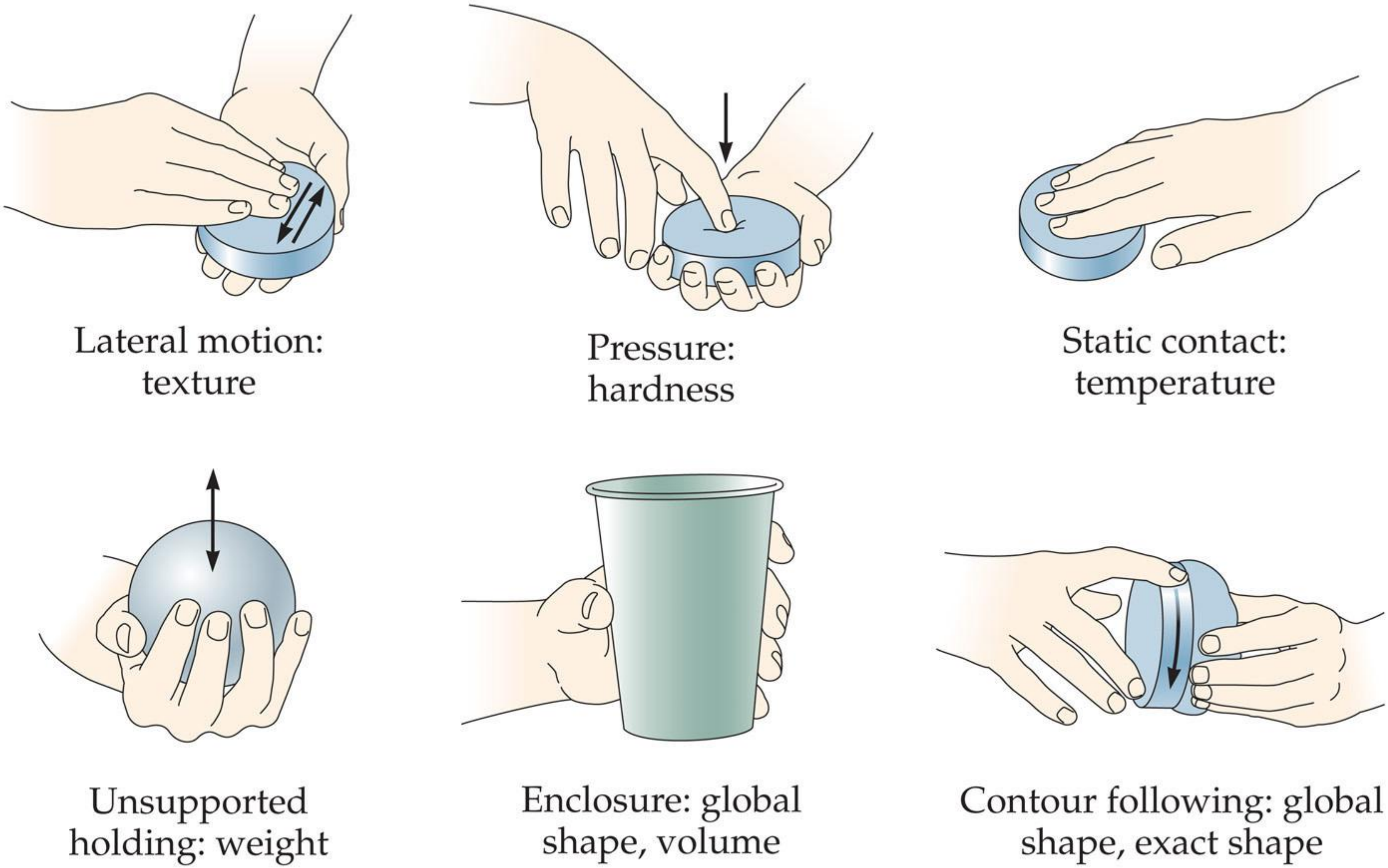


SENSATION & PERCEPTION 4e, Figure 13.17

Action for perception

- Using our hands to actively explore the world of surfaces and objects outside our bodies
  - Exploratory procedure: A stereotypical hand movement pattern used to contact objects in order to perceive their properties; each exploratory procedure is best for determining one or more object properties.
    - Example: To determine roughness of an object, use lateral motion

Figure 13.18 Exploratory procedures described by Lederman and Klatzky, and the object properties associated with each procedure

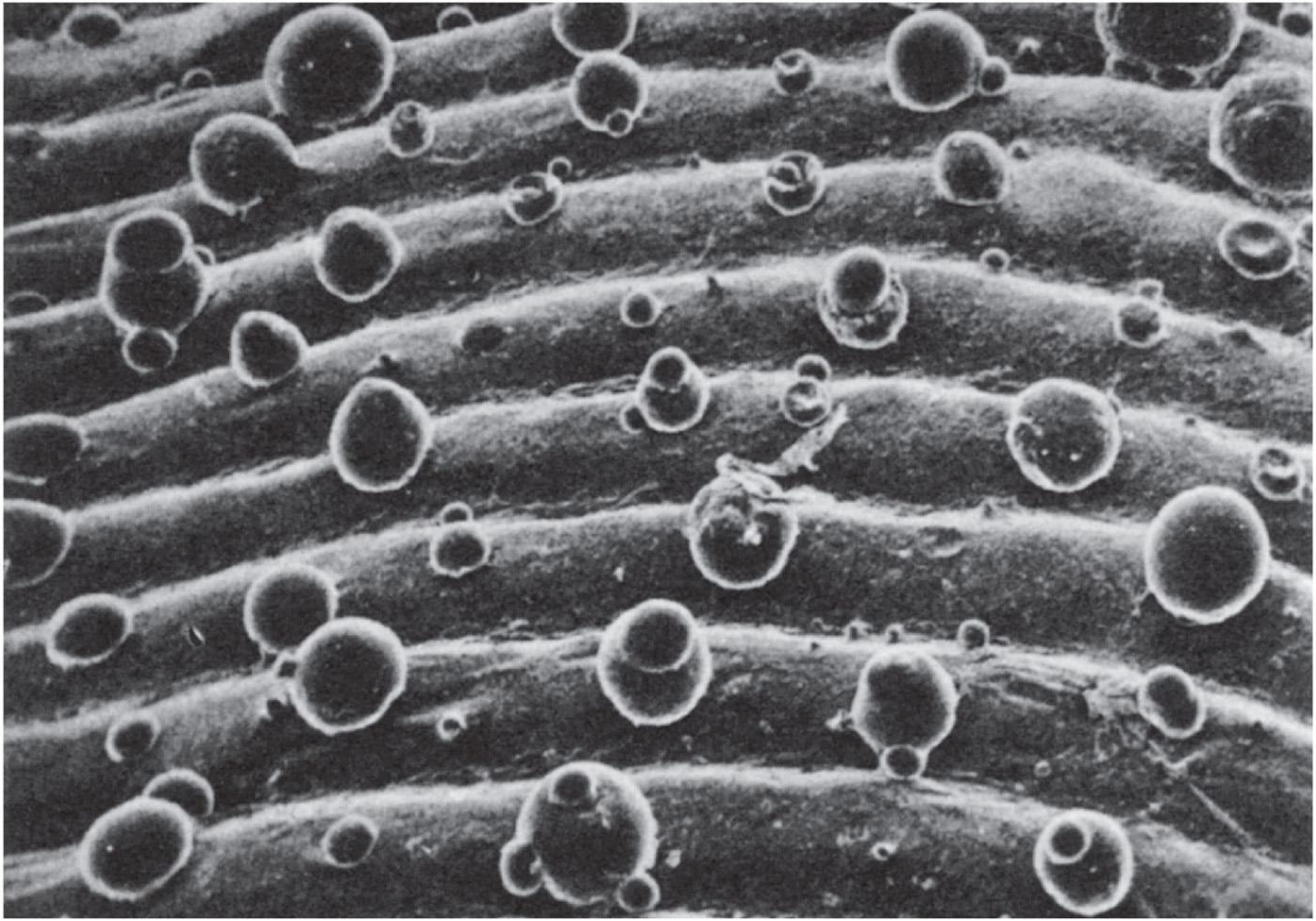


SENSATION & PERCEPTION 4e, Figure 13.18

The role of fingerprints in perception and action

- Ridged fingerprint patterns aid perception of fine surface textures.
  - Fingerprint ridges selectively amplify frequencies from 200 to 300 Hz by a factor of about 100, while filtering out other frequencies.
  - Fits with sensitivity range of FA II receptors.
- Ridged fingerprints may help maintain grip in the presence of moisture.

Figure 13.19 Scanning electron micrograph of the skin ridges on a human index finger pad



***SENSATION & PERCEPTION 4e,* Figure 13.19**

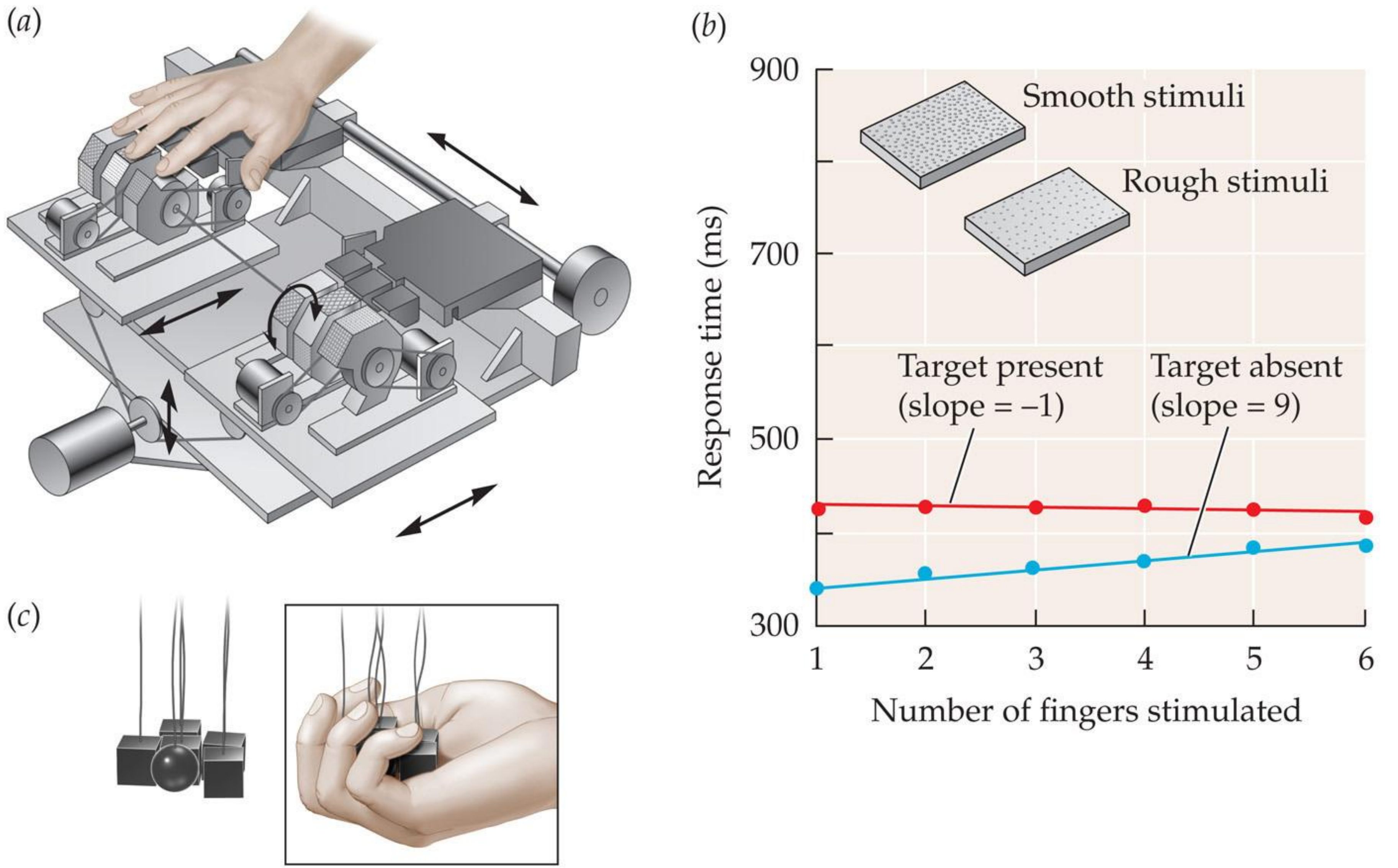
The *What* system of touch

- Geometric properties of objects are most important for visual recognition.
- Material properties of objects are crucial for haptic recognition.
  - Two-dimensional pictures of objects are recognized easily visually but poorly haptically.

Haptic search

- Task: Recognize presence of material properties that are presented haptically to the fingers with a special device.
- Do some material properties “pop out”?
  - *Yes*: Rough among smooth, hard among soft, cool among warm, edged surfaces among smooth surfaces
  - *No*: Horizontal lines among vertical lines
- “Pop out” stimuli for vision and touch are different.

Figure 13.21 An experiment investigating whether touch supports preattentive feature detection

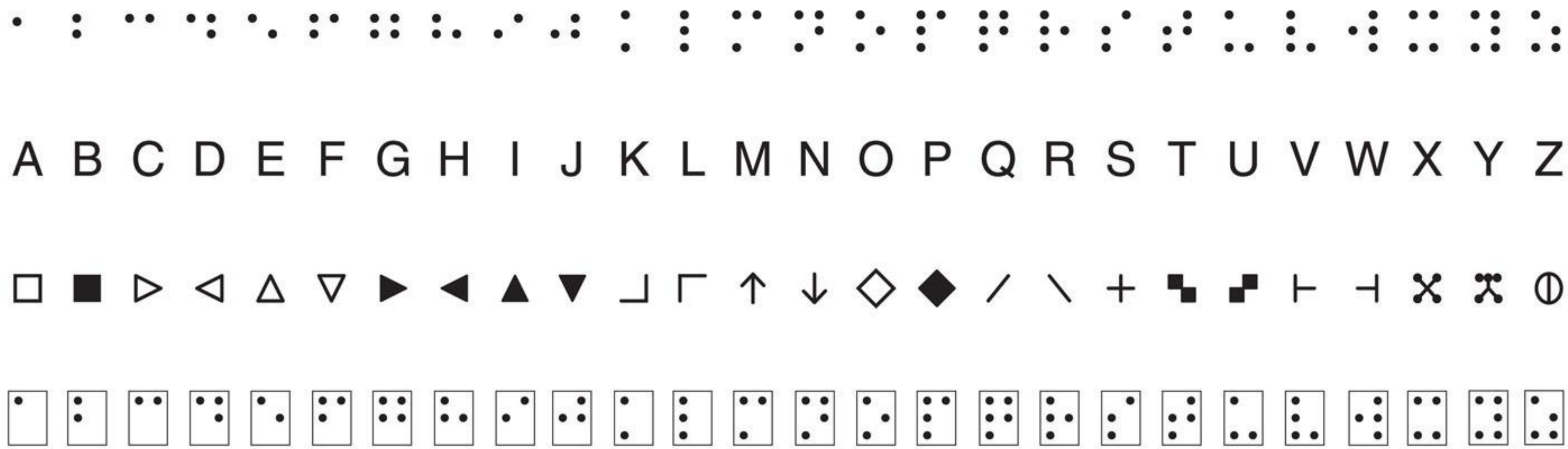


***SENSATION & PERCEPTION 4e*, Figure 13.21**

Perceiving patterns with the skin

- Braille alphabet consists of raised dots
- Loomis: Touch acts like blurred vision when the fingertips explore a raised pattern
  - Visual stimuli blurred to match the acuity of fingertip skin
  - Visual stimuli and haptic stimuli showed same confusion errors

Figure 13.22 Selected character recognition sets used by Loomis, including Braille



***SENSATION & PERCEPTION 4e*, Figure 13.22**

Tactile agnosia

- The inability to identify objects by touch
- Caused by lesions to the parietal lobe

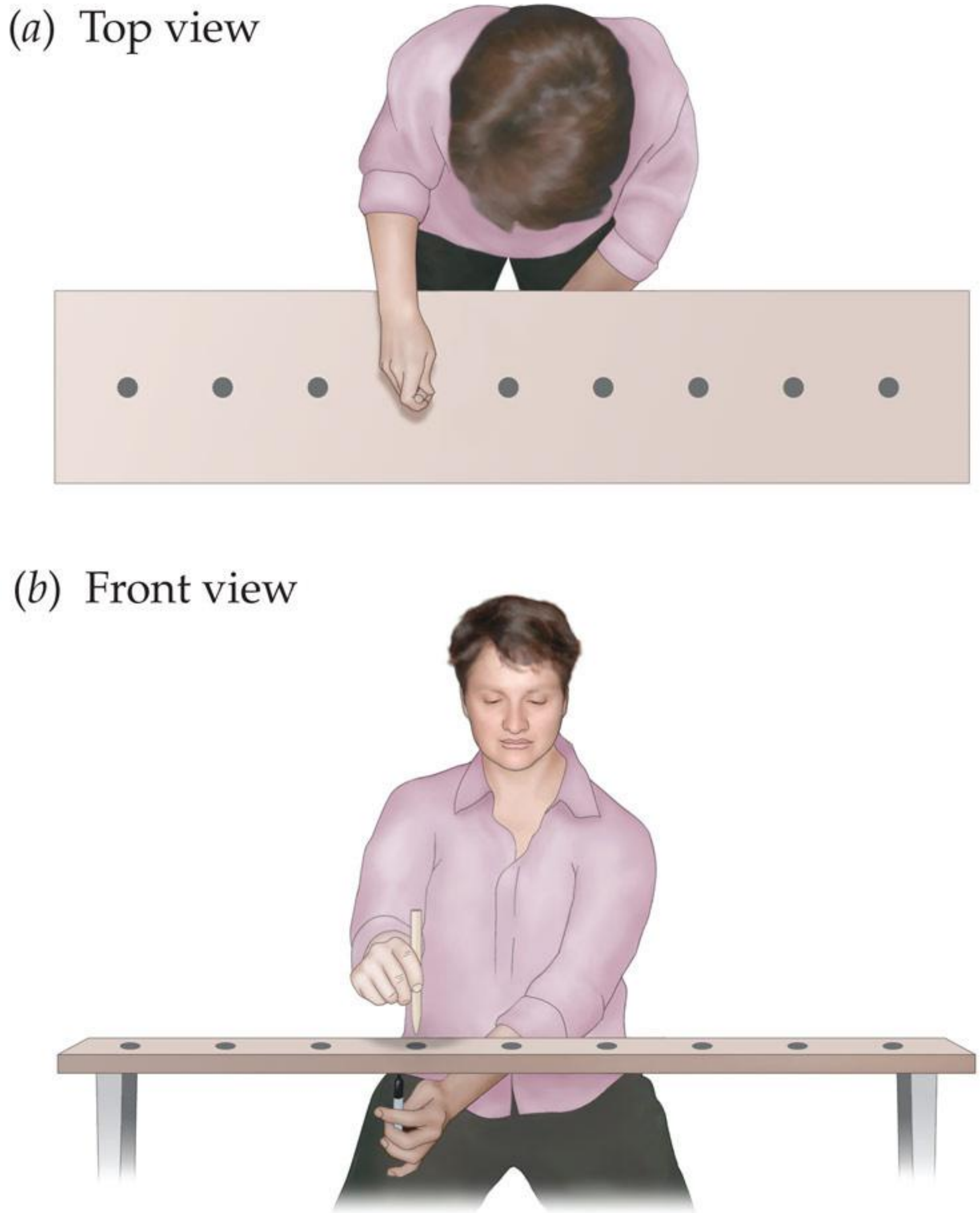
Tactile agnosia (*continued*)

- Patient documented by Reed and Caselli (1994):
  - Tactile agnosia with right hand but not left hand
  - Could not recognize objects such as a key chain in right hand, but could with left hand or visually
    - Rules out a general loss of knowledge about objects
  - Other sensory abilities were normal in both hands

The *Where* system of touch

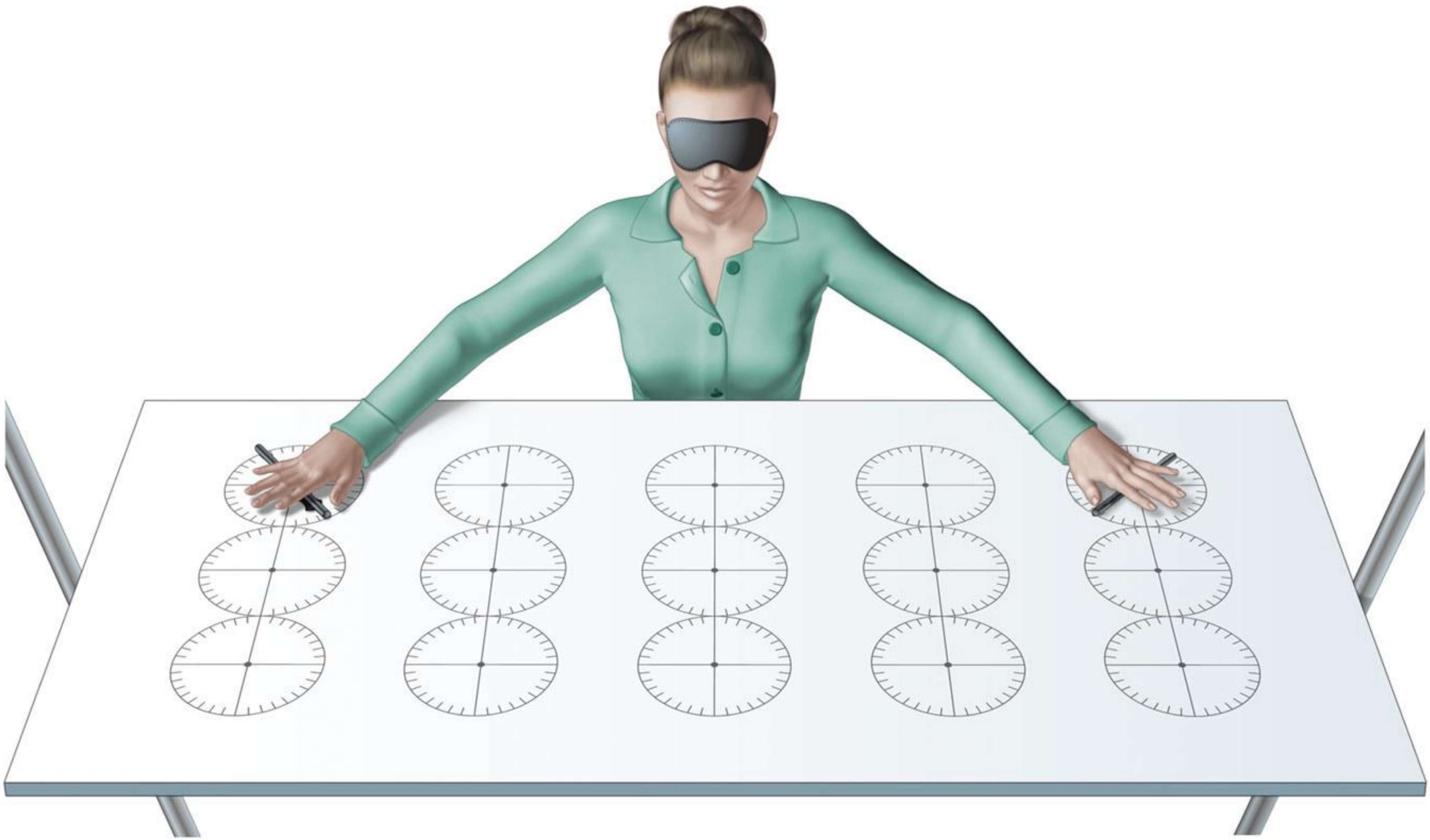
- Knowing where objects are in the environment using only touch perception
  - Example: Finding snooze button on alarm clock in the morning
- Frame of reference: The coordinate system used to define locations in space.
- Egocenter: The center of a reference frame used to represent locations relative to the body.

Figure 13.23 Locating the haptic egocenter



SENSATION & PERCEPTION 4e, Figure 13.23

Figure 13.24 Haptic perception of tabletop space



SENSATION & PERCEPTION 4e, Figure 13.24

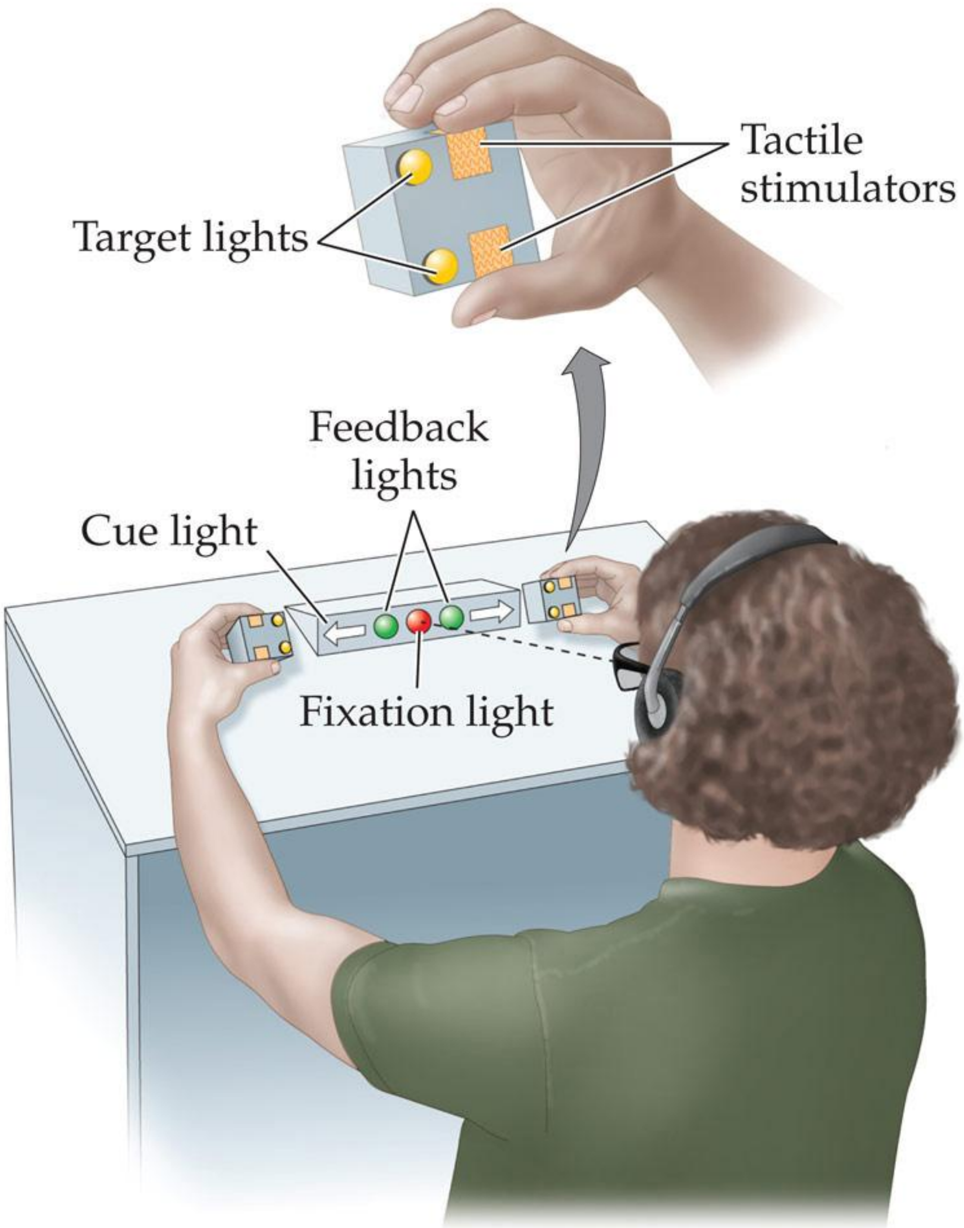
Tactile spatial attention

- Spence, Pavani, and Driver (2000): Spatial cueing paradigm used to test integration of visual and tactile modalities
- Arrow indicated which hand might receive a vibration
  - Vibration could be a pulse or sustained force. Task was to identify which occurred

Tactile spatial attention (*continued*)

- Most cues valid, some invalid
  - Participants faster with valid cues and slower with invalid cues
- Results consistent with analogous experiments conducted in purely visual domain (Chapter 7)

Figure 13.25 Studying competition between sensory modalities



SENSATION & PERCEPTION 4e, Figure 13.25

Social touch

- The influence of touch can extend beyond perception and action in surprising ways.
- Incidental touch can influence social judgments (Ackerman, Nocera, and Bargh, 2010).

Social touch (*continued*)

- Rats who were licked and groomed by their mothers will lick and groom their own pups as well.
- Pups from attentive and remote moms can be switched at birth, and they will "inherit" the behavior of their adoptive mother.

Social touch (*continued*)

- Epigenetic rather than genetic trait
  - Being licked and groomed as a pup turns on those genes for the rest of the rat’s life.
- Pups that were licked and groomed tend to be less timid than those that weren’t.

Interactions between touch and other modalities

- Spence, Nicholls, and Driver (2001) performed a cross-modal version of the Spence, Pavani, and Driver (2000) experiment.
  - Led participants to expect a stimulus to be presented in one modality and sometimes presented it in another

Interactions between touch and other modalities (*continued*)

- Greatest cost for invalid cues occurred when tactile stimulus expected but visual or auditory stimulus presented instead
  - Implies that sense of touch may have a very restricted attentional channel

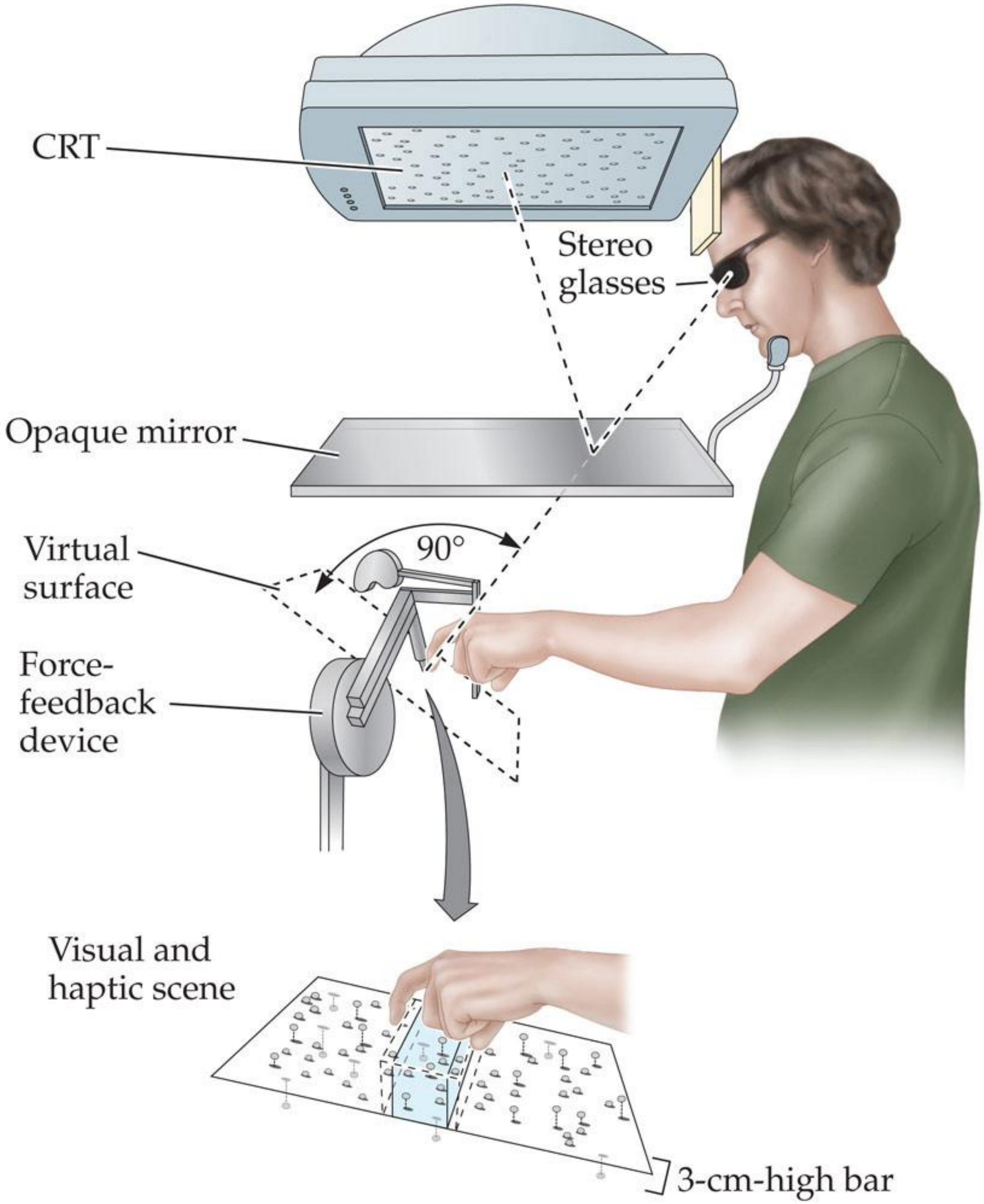
Interactions between touch and other modalities (*continued)*

- Lederman, Thorne, & Jones (1986) showed participants one type of sand paper while they touched a different type but they told them they were the same.
- When asked “How closely packed are the elements on the surface?” they were more influenced by vision.
- When asked “How rough is the surface?” they were more influenced by touch.

Interactions between touch and other modalities (*continued)*

- Ernst & Banks (2002) used an apparatus that provided touch and vision of a virtual display.
- A portion of the surface appeared to be raised.
  - Sometimes the height of the surface was different for vision and touch.
  - Perception was a compromise between the two senses.

Figure 13.26 Testing the integration of sensory modalities



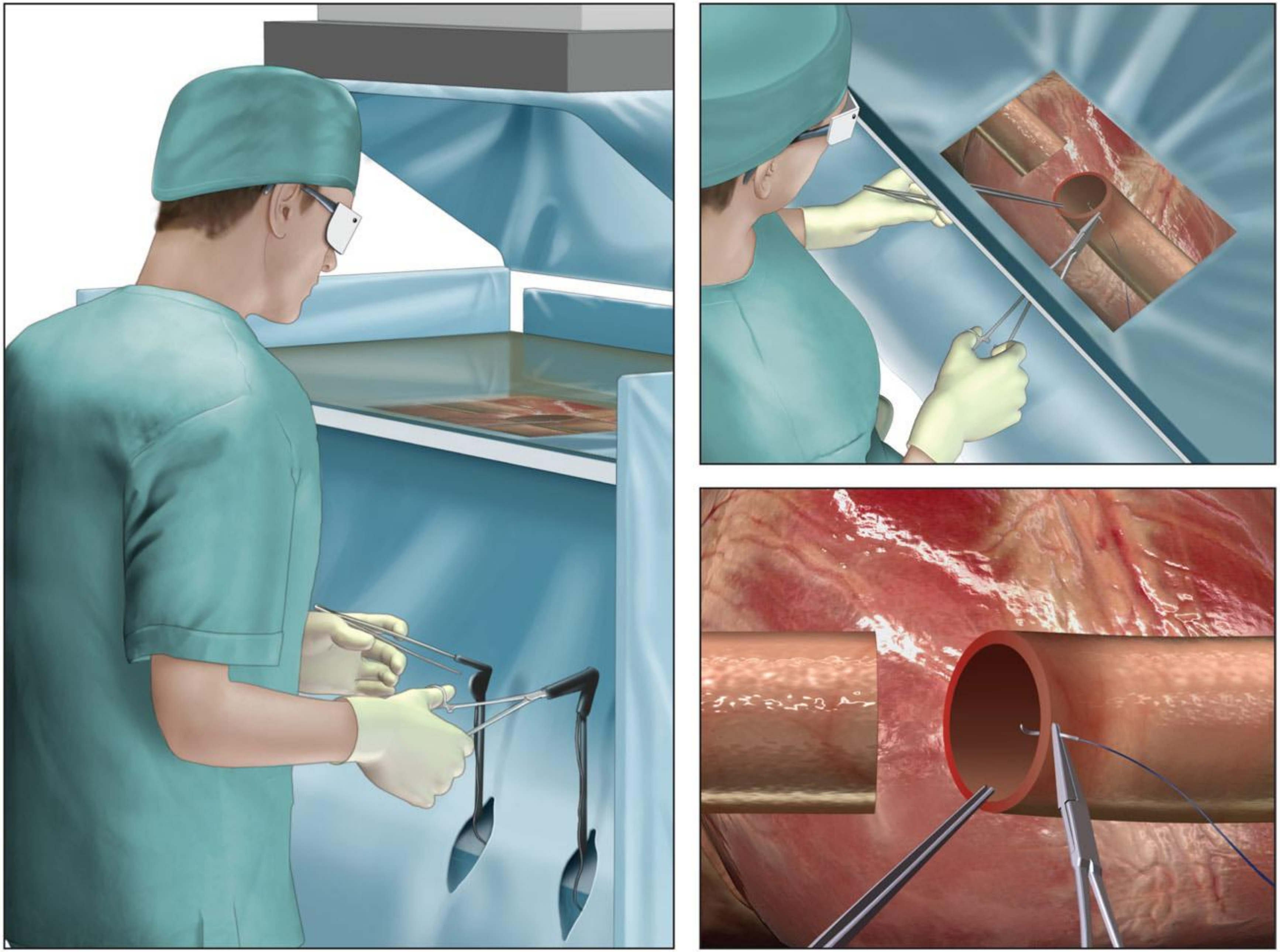
SENSATION & PERCEPTION 4e, Figure 13.26

Sensation & Perception in Everyday Life: Haptic Virtual Environments

Haptic virtual environments: A synthetic world that may be experienced haptically by operation of an electromechanical device that delivers forces to the hand of the user.

- Virtual surgery
  - Efforts are underway to perfect force-feedback devices to allow surgeons to practice complex procedures or conduct remote operations via the Internet.

Figure 13.28 A virtual surgical trainer



SENSATION & PERCEPTION 4e, Figure 13.28