

Today we will focus on the somatic sensory system also called the somatosensory system.

Responsible for a bunch of fairly important things including touch or tactile discrimination, vibration, pressure, limb positioning or proprioception, pain, temperature.

Monitors external and internal forces acting on the body— e.g. touch is external, proprioception/self positioning is internal.

Gives rise to our ability to identify objects, also called stereognosis.

And of course helps us become alarmed to potentially dangerous environments.

soma

: the parts of an organism other than the reproductive cells

: the body as distinct from the soul, mind, psyche

Sensory systems:

- The nervous system consists of discrete systems for each of the sensory modalities (touch, vision, hearing, taste, smell)
- Each functional system involves several CNS regions that carry out different types of information processing
- Identifiable pathways link the components of a functional system
- Each part of the brain projects in an orderly fashion onto the next, creating sensory (e.g. topographic) maps. Neural maps not only reflect the position of receptors on a sensory surface, but also their density
- Functional systems on one side of the body generally respond/control the other side of the body

Somatic sensation. The sense of self. The where and also partially what of being a self within a spatiotemporal domain of reference. The sense of being one. Being one. One. An animal entity's core.

Somatic sensory system

1. proprioceptive input (positioning of self– muscle fiber feedback)
 - Monitoring the external and internal forces acting on the body at any moment
2. tactile input (touch– vibration, pressure, stretch)
 - Discrimination of shapes and textures of objects
3. nociceptive input (pain– injury, extreme temperatures, pH)
 - Detection of potentially harmful circumstances

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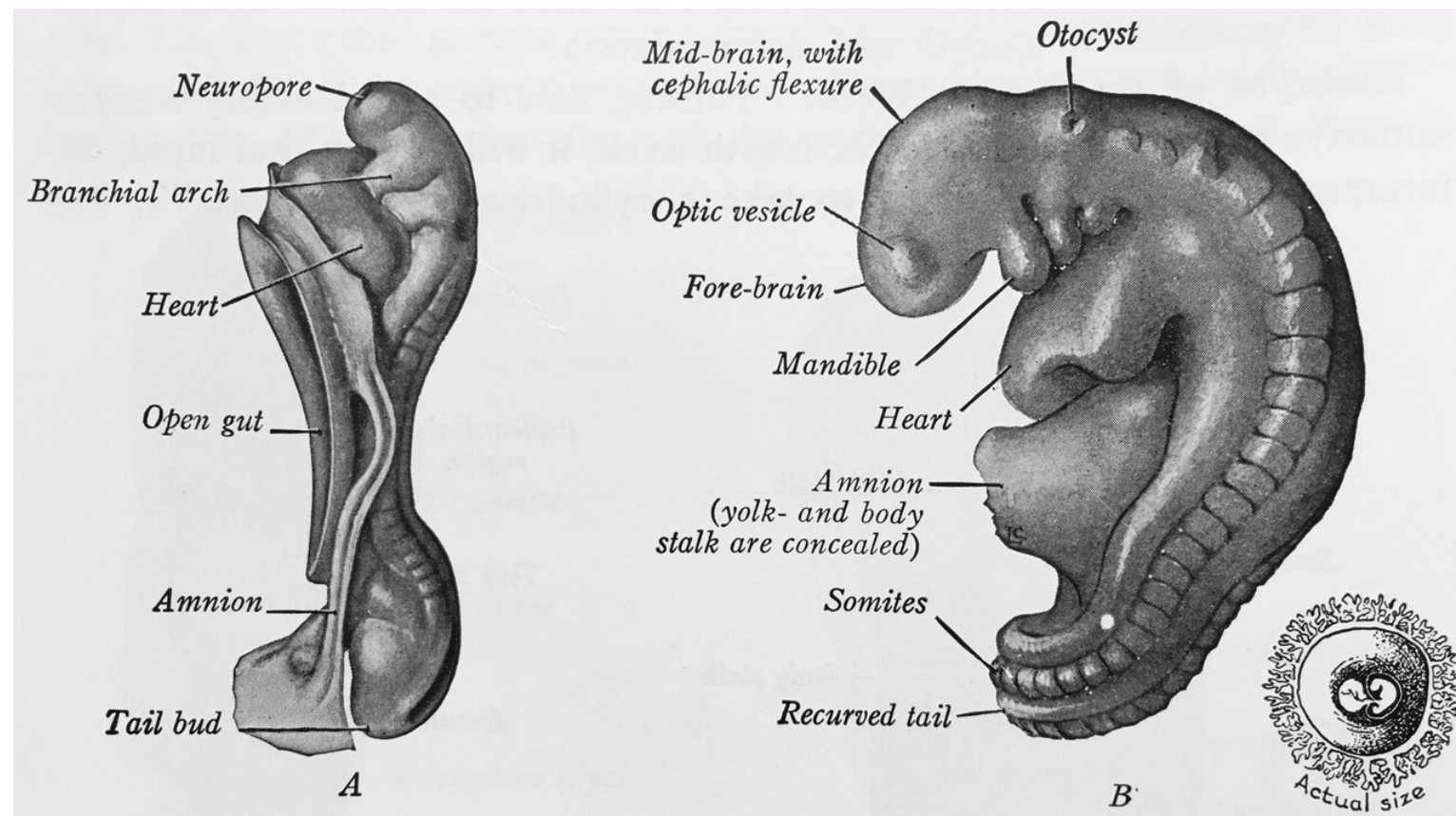
Overview of somatic sensory system

- Specific receptor neurons located in skin, muscle, or joints receive stimuli
- Information is carried to brain via the spinal cord, brainstem, thalamus, to the post central gyrus of the parietal lobe, which in turn project to higher order cortical areas
- Projections are topographic with respect to body region, and the amount of cortical space allocated to various body parts is proportional to the density of sensory receptors in that area

Dermatomal segments

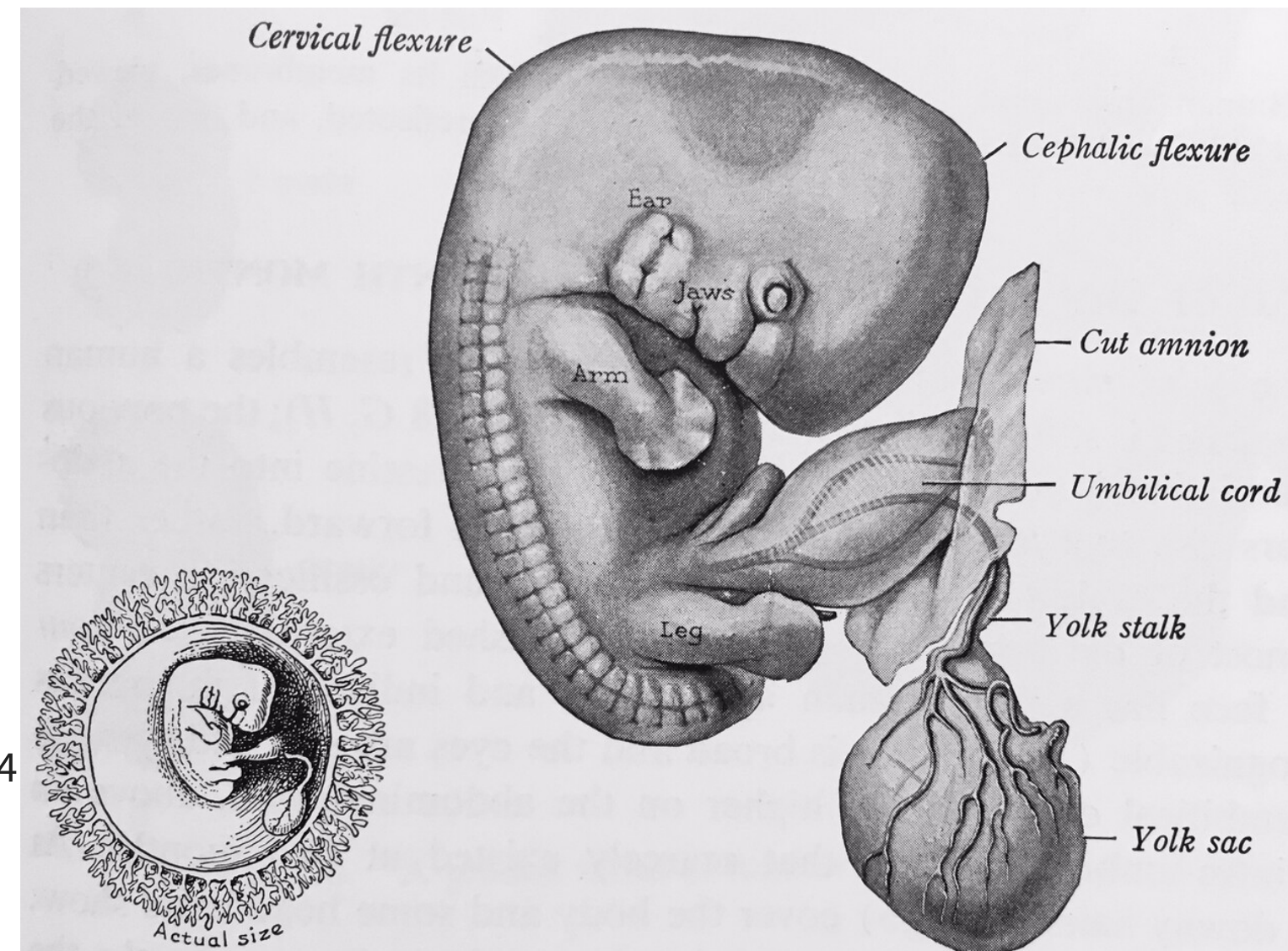
...from the embryonic somites

Human embryo at three to four weeks



24d, 2.6mm, 19somites; 26d, 3.6mm, 25somites; *Dev Anatomy* Arey 1954

Human embryo at four to six weeks



28d, 5mm; 35d, 8mm; 42d, 12mm; *Developmental Anatomy* Arey 1954

Speaker notes

- somites, metameres
- : mesoderm separates into localized structures called somites
- : origin of the dermatomal segments : happens around neural tube closure, third week of gestation in human
- : develop in rostral to caudal direction
- : positioning regulated by the highly conserved hox genes
- : formed every 90 minutes in chick embryo
- : chicken 50 somites, mice 65 somites, snakes 500, human 39-44
- : somites become the dermatomes and myotomes that make up the vertebrae, tissue regions of skin and muscle

Developmental Anatomy 1924, 1954 Arey p. 98

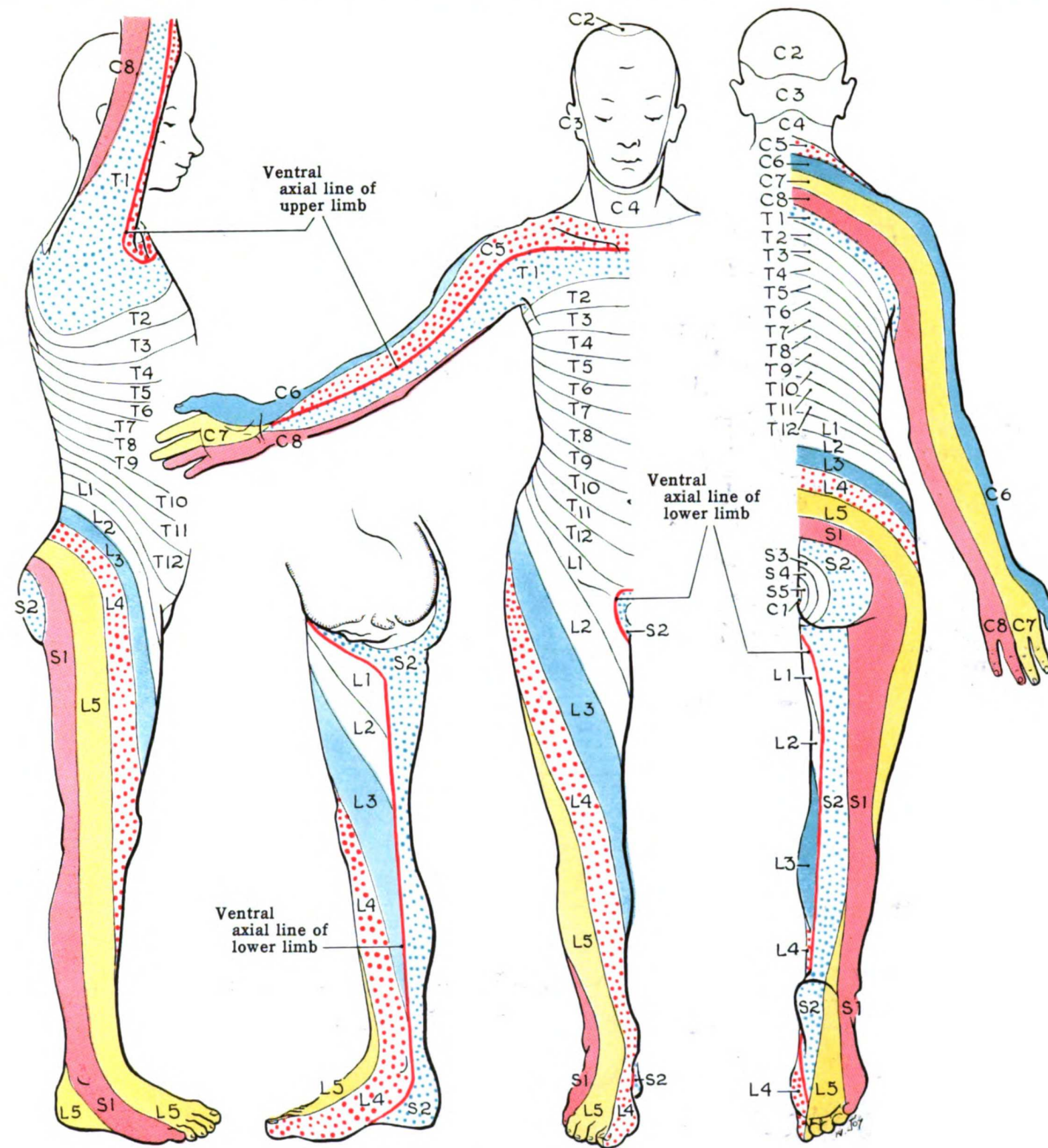
Fig. 74 Human embryos of twenty-four and twenty-six days, viewed from left side. A, Atwell embryo of 26 mm, with nineteen somites (Streeter; x23); B, 3.6mm, embryo with twenty-five somites (x16)

Developmental Anatomy 1924, 1954 Arey p. 99

Fig. 75 Human embryos of four and five weeks, viewed from the left side. A At 5 mm. B, at 8 mm Fig. 76. Human embryo of six weeks (12 mm). viewed from the right side.

Dermatomal segments of the body

the human dermatome



Grant, *An atlas of anatomy* 1962 [Public Domain](https://en.wikipedia.org/wiki/Public_domain)

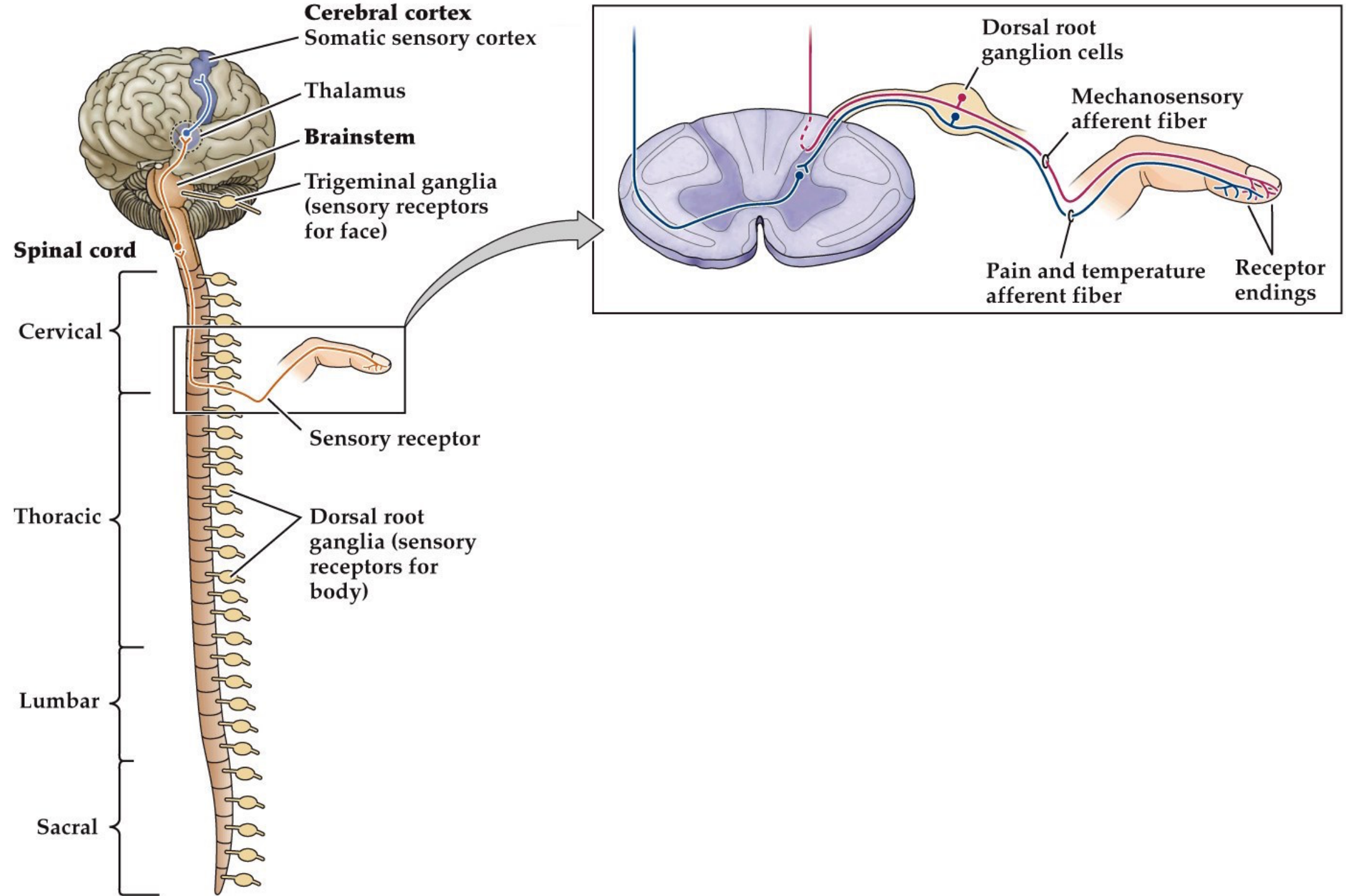
Somatosensory pathway— from somatic sensory neuron to cortex

Speaker notes

We've already become aware that the dorsal root ganglia contain sensory neurons that act as sensory receptors for the body with the cell body located in the ganglion and processes extending to the sensory periphery— e.g. this mechanosensory afferent fiber connected to your index finger, or a proprioceptive neuron sensing internal muscle stretch connected to your knee joint for the myotactic reflex that we've discussed previously.

In this inset you see both mechanosensory and pain sensitive fibers connected to the finger— notice that these are coming from two different neurons (red and blue) and the ascending process from the DRG neurons course through the spinal cord to higher brain regions through different routes. *anterolateral tract vs dorsal column*. More on this later.

Touch and pain have different routes to the brain



Neuroscience 5e Fig. 9.1

Somatic sensory receptors

Can vary characteristically by

- Functions– pain, temperature, touch, and proprioception
- Morphologies– free nerve endings or encapsulated
- Conduction velocities– fast vs. slow
- Locations– skin, muscle, tendon, hair
- Rates of adaptation– slow vs. fast

This table summarizes the somatosensory afferents types, and variety in their functions, morphologies, and AP conduction velocities.

The fastest ones are...

The slowest ones are...

Tab. 1 after Rosenzweig 2005

Types of somatosensory afferents

sensory function	receptor type	afferent axon type (alt name)	axon diameter (μm)	conduction velocity (m/s)
proprioception	muscle spindle	$A\alpha$ (Ia + Ib), myelinated	13–20	80–120
touch	Merkel, Meissner, Pacinian, and Ruffini cells	$A\beta$ (II), myelinated	6–12	35–75
pain, temperature	free nerve endings	$A\delta$ (III), myelinated	1–5	5–30
pain, temperature, itch	free nerve endings	C, unmyelinated	0.2–1.5	0.5–2

Proprioception are stimuli that are produced and perceived within an organism, such as the positioning and movement of the body

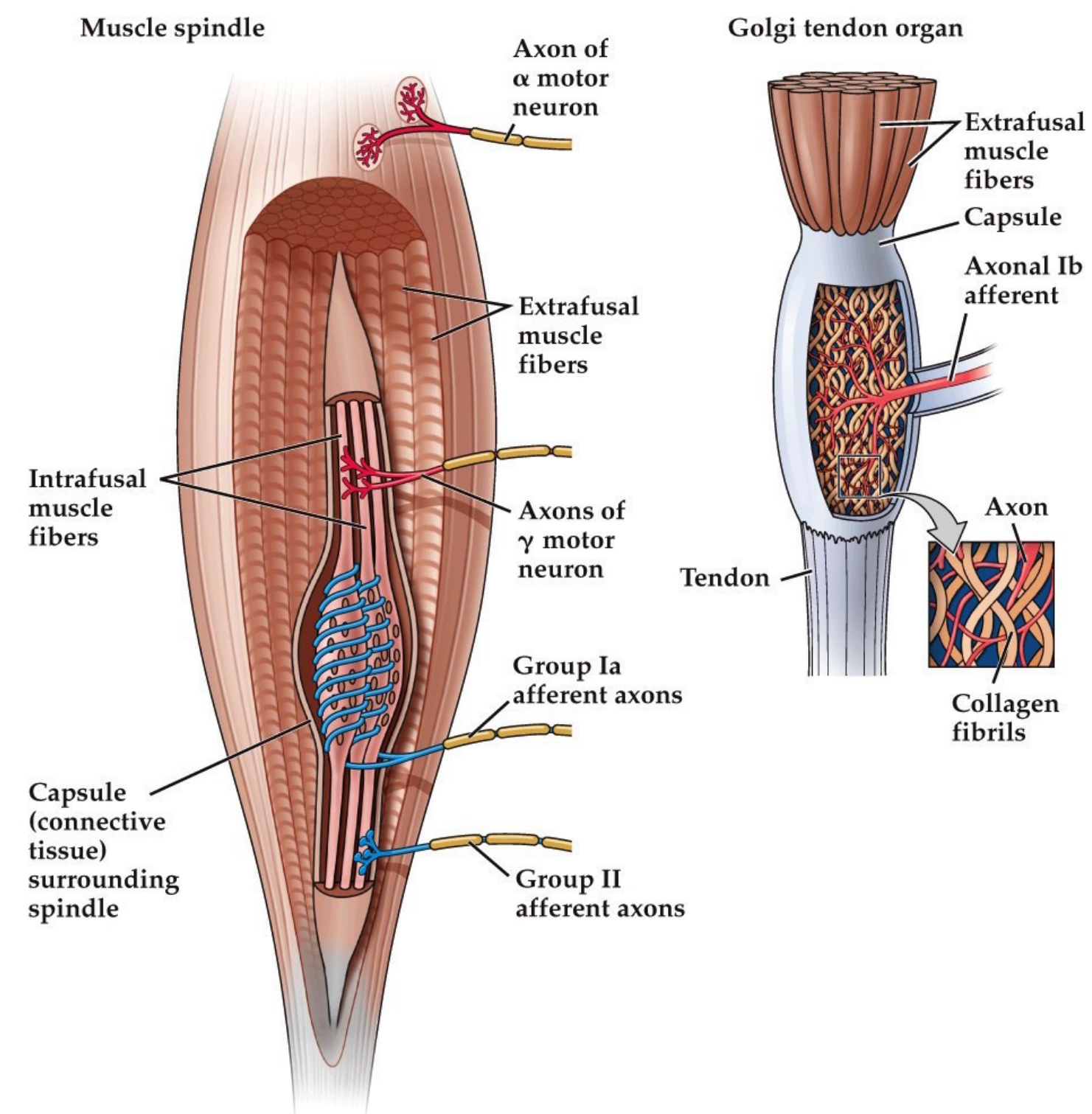
proprioceptive and vestibular system input is integrated within the brain to cause a perception of body position, movement, and acceleration

Provides feedback to γ motor neurons that change spindle length to compensate as needed

Proprioception

- Sensory feedback information about **self**. Where are my limbs and other body parts?
- Muscle spindles– sensory organ inside muscles. Consists of 'intrafusal' muscle fibers enveloped by fast Group A α (Ia) sensory neuron afferents. Signals present muscle stretch.
- Golgi tendon organs– sensory organ between muscle fiber and tendon. Consists of connective tissue enveloped by fast Group A α (Ib) sensory neuron afferents. Signals present muscle force.

Proprioceptors provide information about the position of body parts

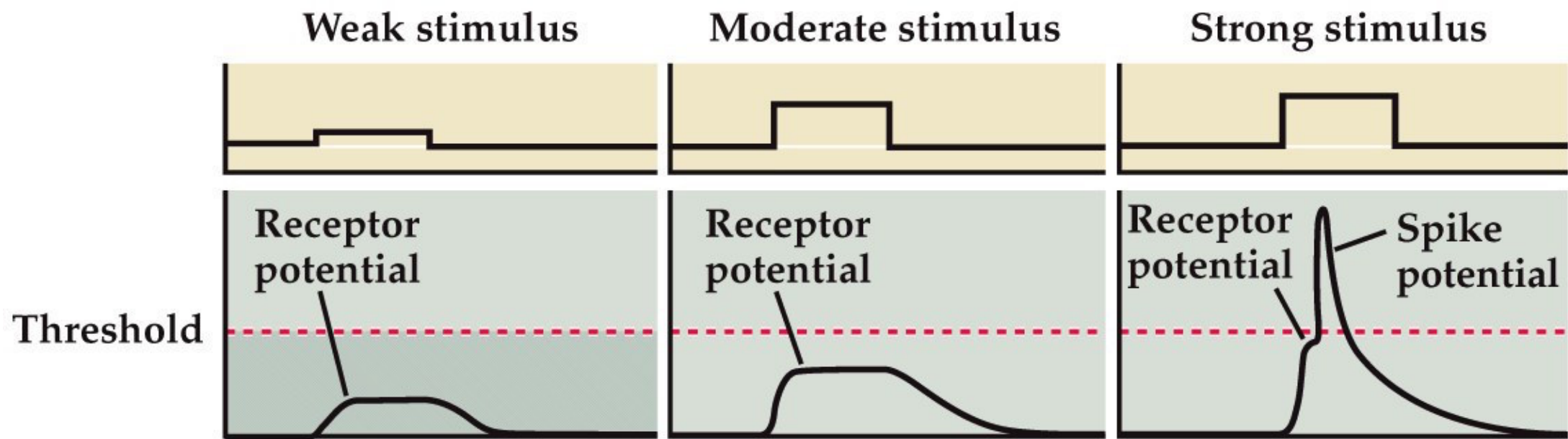
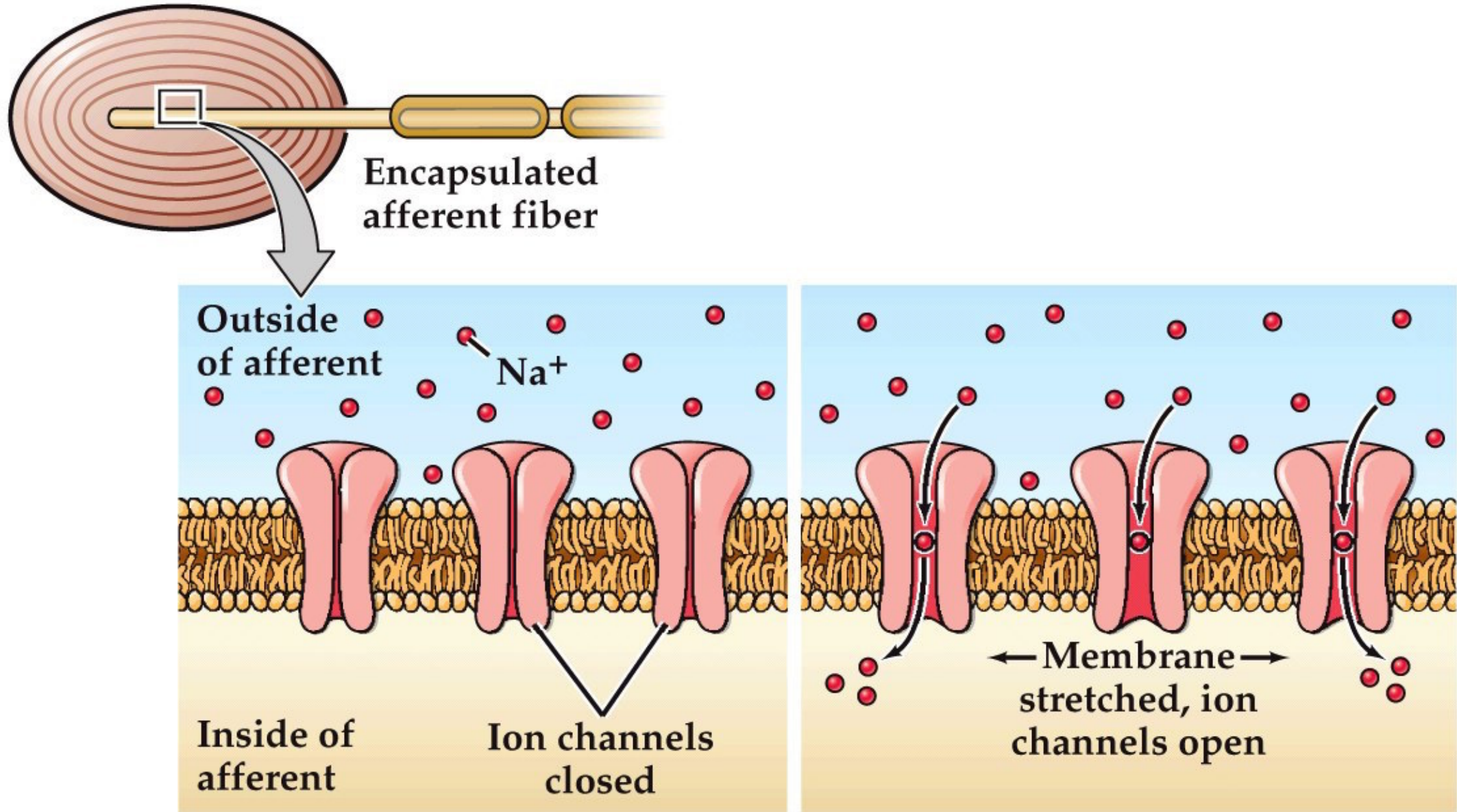


Neuroscience 5e Fig. 9.7

General properties of sensory receptors

- Stimuli applied to skin, deforms or changes the nerve endings, produces a receptor potential that triggers an action potential
- Quality of stimulus (what it represents and where it is) is determined by the relevant receptor and the afferent neuron's targets in the brain
- Quantity or strength of stimulus is determined by the rate of action potential discharge

Somatosensory receptors



Neuroscience 5e Fig. 9.2

Speaker notes

The sensation of touch, pain, or temperature all starts with specialized receptors and nerve endings in the skin. In all cases ion channels open on the receptor neuron ending that can depolarize and initiate an AP with a sufficiently strong stimulus.

from: <http://www.ncbi.nlm.nih.gov/gene/63895>

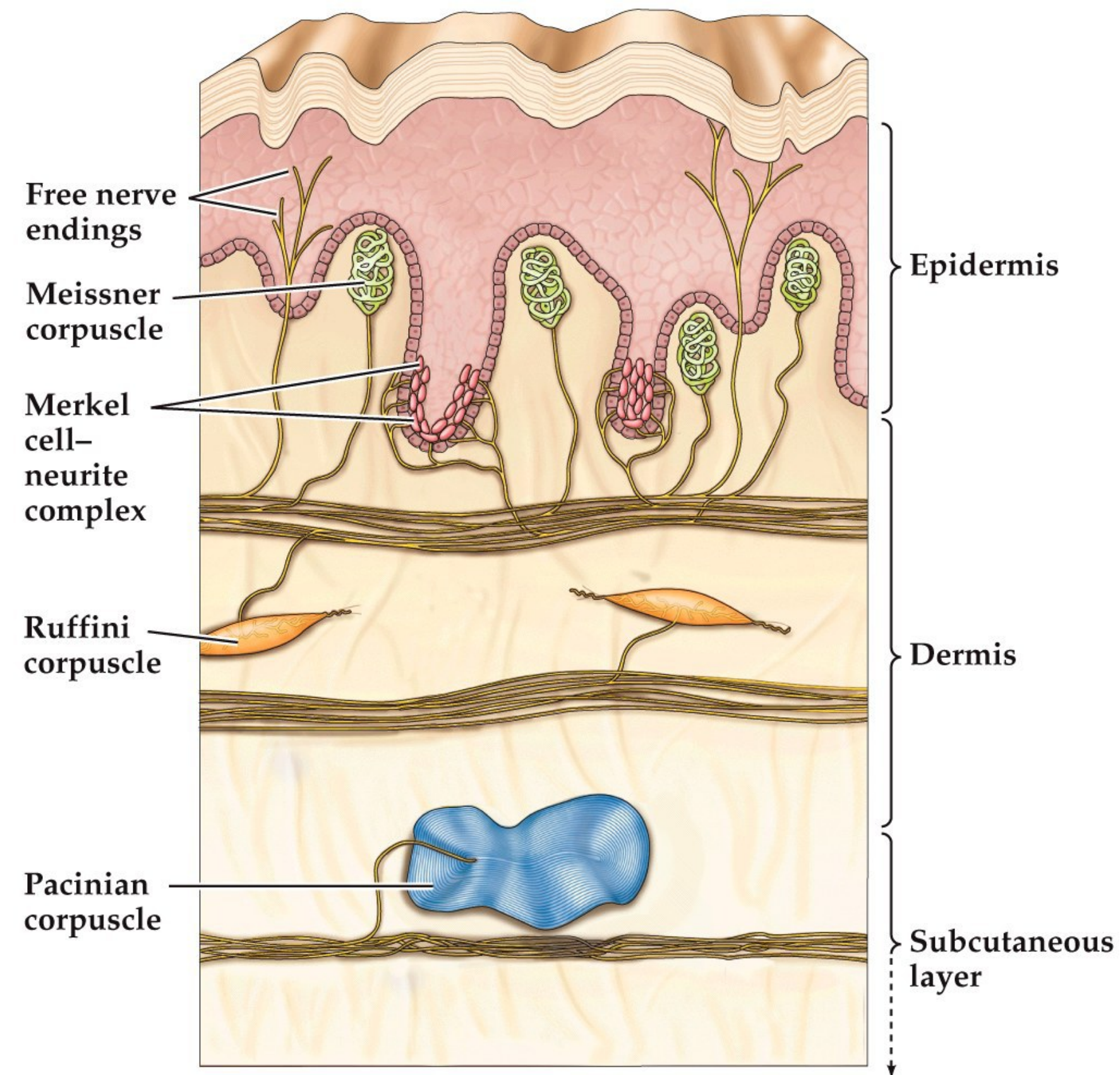
- example in this fig looks like a pacinian corpuscle
- piezo type mechanosensitive ion channel component 2
- protein encoded by this gene contains more than thirty transmembrane domains and likely functions as part of mechanically-activated (MA) cation channels
- channels serve to connect mechanical forces to biological signals

piezo
: greek for push

Piezoelectric Effect
: ability of some materials to generate an electric charge in response to applied mechanical stress
: reversible: mechanical stress \leftrightarrow electricity
: gas stoves, cigarette lighters
: piezoelectric ceramics (Lead zirconate titanate or PZT $\text{Pb}[\text{Zr}_x\text{Ti}_{1-x}]\text{O}_3$) and single crystal materials (gallium phosphate, quartz, tourmaline)

- piezo for mechanical stress
- ASIC for acid/low pH sensing
- TRP for hot/cold

Skin harbors morphologically distinct mechanoreceptors



Neuroscience 5e Fig. 9.5

Mechanoreceptors

- Provide information about touch, pressure, vibration, and cutaneous tension
- Four major types of encapsulated mechanoreceptors:
 - Merkel's disks
 - Meissner's corpuscles
 - Ruffini's corpuscles
 - Pacinian corpuscles
- Called low-threshold mechanoreceptors because even weak stimulation causes them to fire action potentials. Innervated by large myelinated axons (type A β fast)

Properties of mechanoreceptor afferents

type	Merkel	Meissner	Ruffini	Pacinian
location	tip of epidermal sweat ridges	dermal papillae (close to skin surface)	dermis	dermis and deeper tissues
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	tangential force, hand shape, motion direction	perception of distant events through transmitted vibrations, tool use
effective stimuli	edges, points, corners, curvature	skin motion	skin stretch	vibration
receptive field area	9 mm^2	22 mm^2	60 mm^2	entire finger or hand
innervation density (finger tip)	100/ cm^2	150/ cm^2	10/ cm^2	20/ cm^2
spatial acuity	0.5 mm	3 mm	7+ mm	10+ mm
response to sustained indentation	sustained (slow adaptation)	none (rapid adaptation)	sustained (slow adaptation)	none (rapid adaptation)
frequency range	0-100 Hz	1-300 Hz	0-? Hz	5-1000 Hz
peak sensitivity	5 Hz	50 Hz	0.5 Hz	200 Hz
best threshold for rapid indentation	8 μm	2 μm	40 μm	0.01 μm
mean threshold for rapid indentation	30 μm	6 μm	300 μm	0.08 μm

Speaker notes

Two broad classes based on receptive field area, innervation density-- both classes (ones with small receptive fields vs large receptive fields) have subtypes that have either sustained activity upon depression or transient activity just at when the stimulus is changing

- receptive fields as measured with rapid 0.5 mm indentation
- table after K.O. Johnson 2002

Work

: $W = Fs$, force*displacement (N-M) : joules newton-meters, N-M : force over time

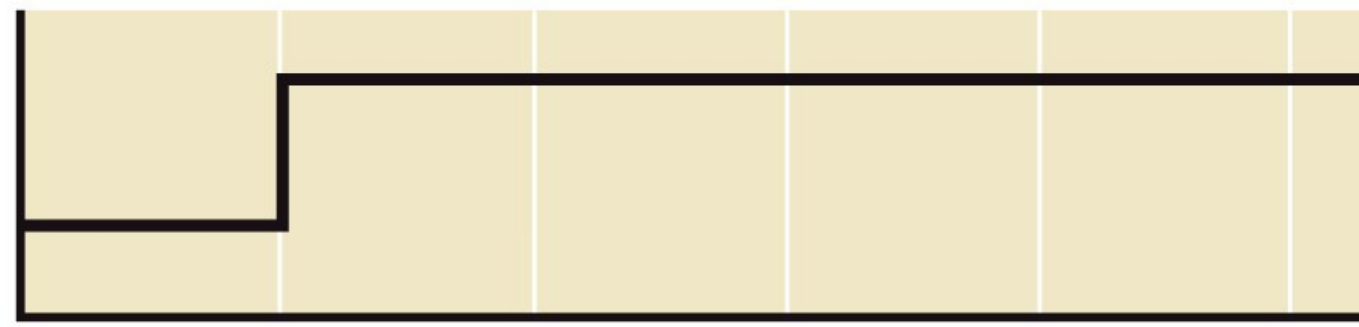
: no displacement, no work

: no work in direction orthogonal to displacement

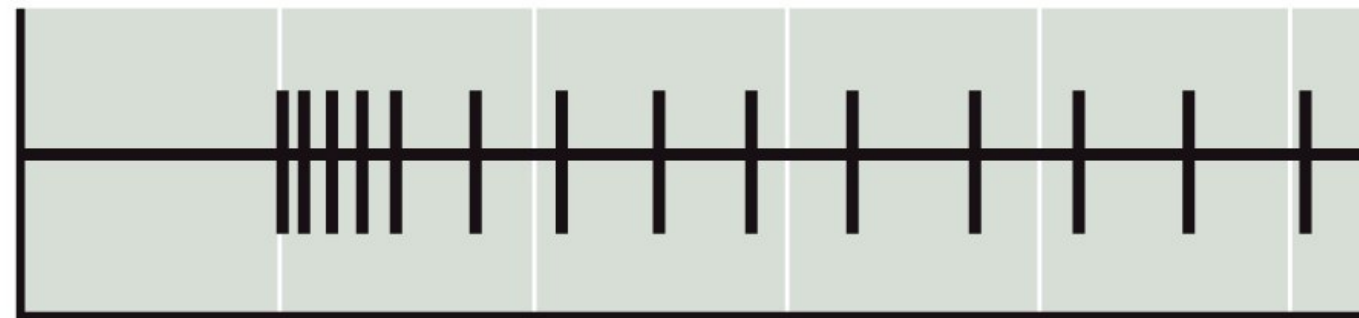
Another type of somatosensory afferent variability I mentioned was rate of adaptation– this figure highlights this difference where if we were performing extracellular electrode recordings close to somatic sensory we find that some types adapt slowly, with sustained spiking as a stimulus stays on, whereas others adapt rapidly with their spiking activity strong at the beginning of the stimulus but quiet as the stimulus is maintained.

Slowly adapting and rapidly adapting mechanoreceptors respond differently to stimulation

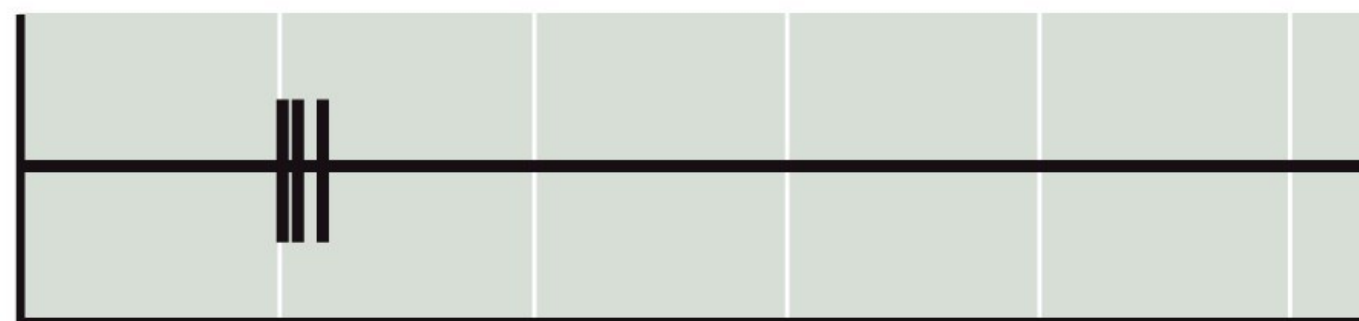
Stimulus



Slowly adapting



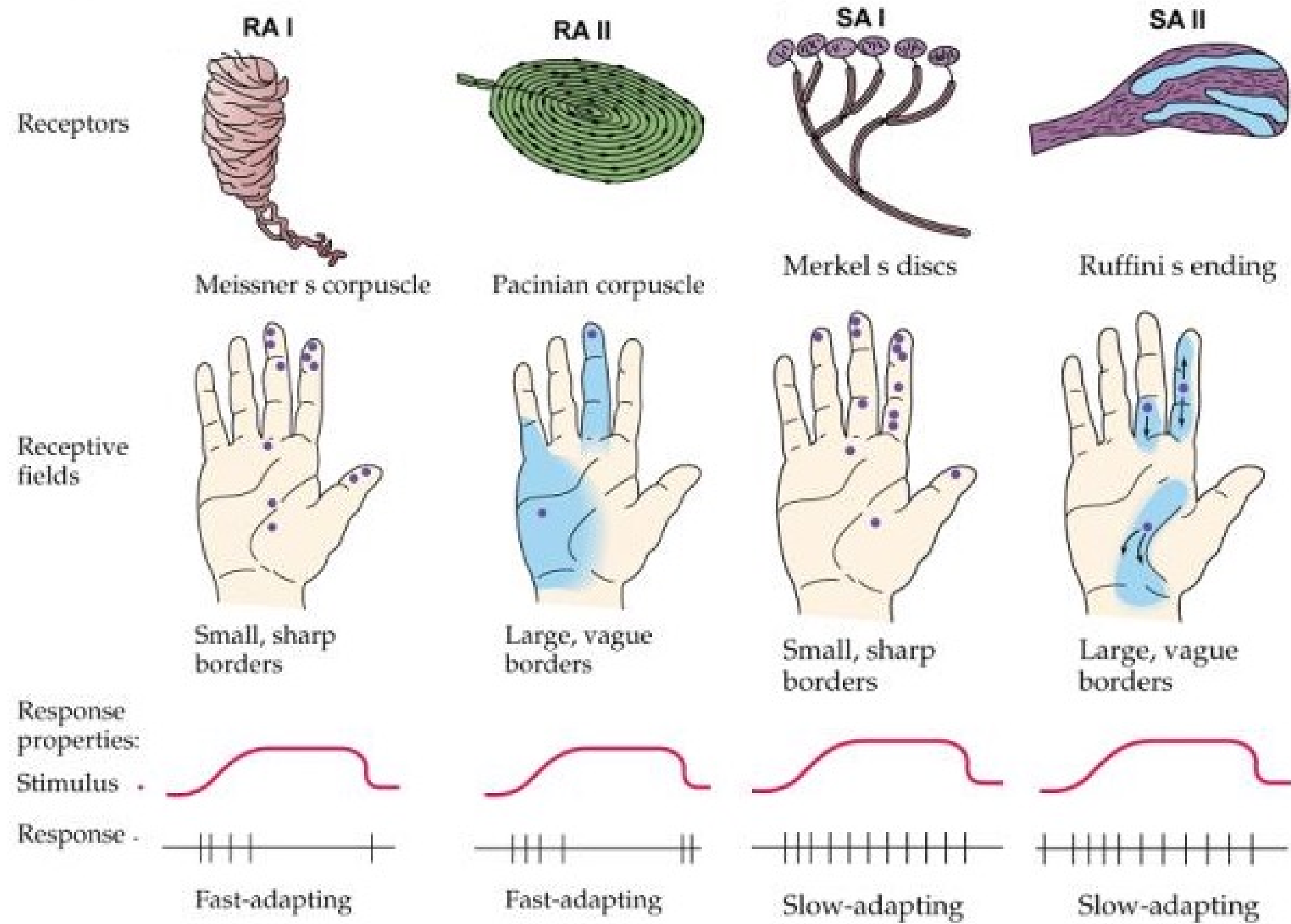
Rapidly adapting



0 1 2 3 4

Time (s)

Cutaneous mechanoreceptors



Neuroscience 2e, Mechanoreceptor types

from: <http://www.ncbi.nlm.nih.gov/gene/63895>

-piezo type mechanosensitive ion channel component 2

-protein encoded by this gene contains more than thirty transmembrane domains and likely functions as part of mechanically-activated (MA) cation channels

-channels serve to connect mechanical forces to biological signals

-

<http://www.nature.com/nature/journal/v509/n7502/full/nature13251.htm>
2014

-<http://www.ncbi.nlm.nih.gov/pubmed/25471886> 2014

Merkel's disks

- Located in epidermis, precisely aligned with the ridges (finger print part of fingers)
- 25% of the mechanoreceptors in the hand
- Are particularly dense in finger tips, lips, and genitalia
- Slow adapting, selective stimulation leads to the feeling of light pressure
- Have small receptive fields

Meissner corpuscle

- Located in the superficial layers of the skin, between the dermal papillae just beneath the epidermis
- Generate rapidly adapting action potentials after minimal stimulation. Adapt fast
- Have small receptive fields
- Account for 40% of the sensory innervation of the human hand. Particularly good in transducing info about low-frequency vibrations
- Detects movement of textures across the skin

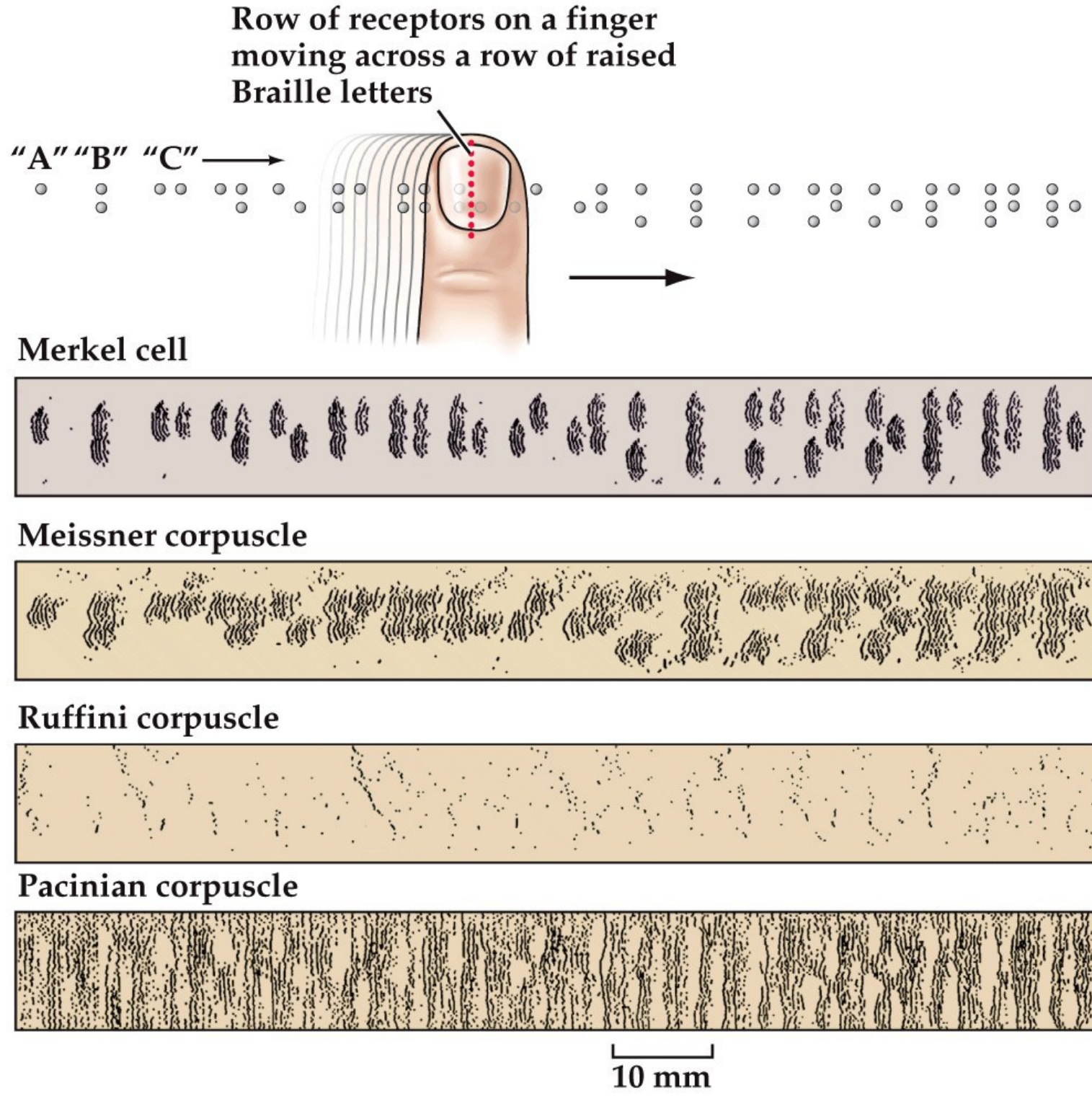
Ruffini's corpuscles

- Lie parallel to the skin
- Large receptive fields
- Detect cutaneous stretching produced by digit or limb movements
- 20% of receptors in hand
- Slow adapting

Pacinian corpuscles

- Have large encapsulated endings located in subcutaneous tissue
- The onion-like capsule acts like a filter allowing in only high frequency stimulation
- Adapts more rapidly than Meissner's and has a lower response threshold
- Has large receptive fields
- Stimulation induces a sense of vibration or tickle
- Involved in the discrimination of fine surface textures
- 10-15% of cutaneous receptors in the hand

Activity patterns in different mechanosensory afferents while Braille is read



Neuroscience 6e/5e Fig. 9.6; from Phillips 1990

Speaker notes

Each of the four raster plots show extracellular recordings from single mechanosensory afferent fibers. Each dot represents the time (x axis) in which an action potential occurred as a pattern of braille dots was moved across the finger. The pattern was then displaced a small distance (relative to tip of finger) and the recording was made again, being repeated numerous times to give the y axis for each plot.

Horizontal line of dots in the raster plot represents the pattern of activity in the afferent when moving the pattern across the finger. The pattern position is then displaced slightly by a small distance and then the pattern is moved again and the spike pattern is displayed on the next row.

Individual Braille dots can be distinguished in the pattern of Merkel afferent neural activity

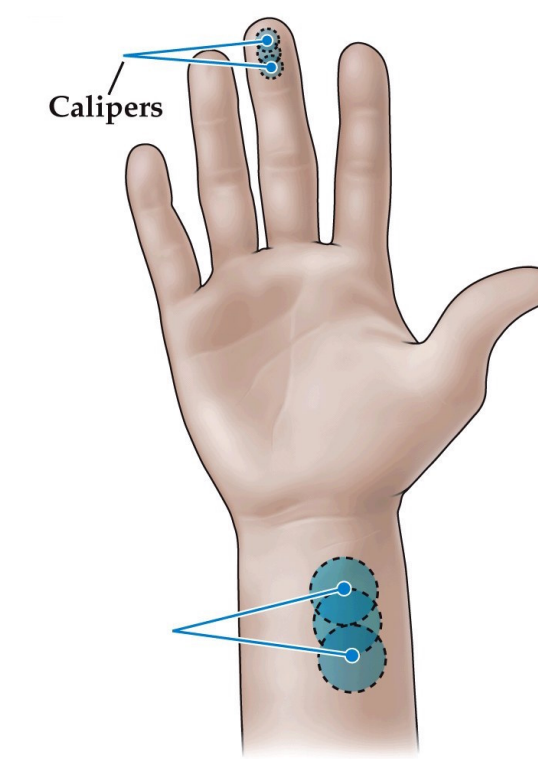
Actually original work done in macaque monkey (Johnson 1981, J Physiol). Rotating drum braille pattern stimulator.

Differences in mechanosensory discrimination across the body surface

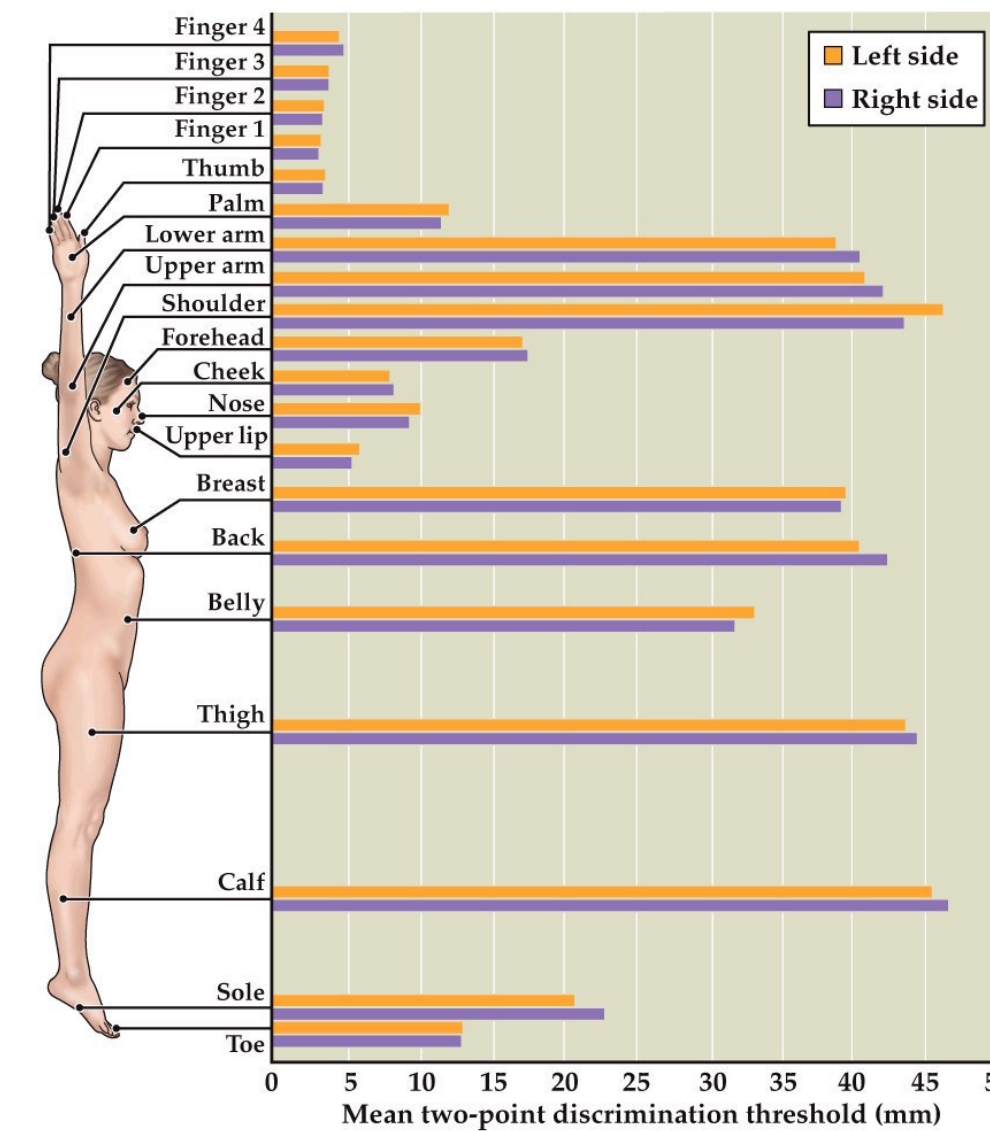
- The accuracy of our sense of touch is not the same all over the body
- Can use two-point discrimination tests to show this
- Fingers can distinguish things 2 mm apart, forearms 40 mm apart
- Mechanosensory receptors are more numerous in finger tips and have smaller receptive fields
- Doesn't explain everything about ability to discriminate two points. The CNS is also involved with discrimination. Two point thresholds vary with practice, and depend on the stimulus

Receptive field size across the body surface

- **Receptive field (RF)**– the area in the periphery within which sensory stimulus can modulate the firing of the sensory neuron
- **Spatial resolution of the RF:**
 - **Size**– smaller RF, higher resolution
 - **Density**– higher cell density, higher resolution
 - **Two-point discrimination test**



Neuroscience 5e Fig. 9.3



Neuroscience 5e Fig. 9.3

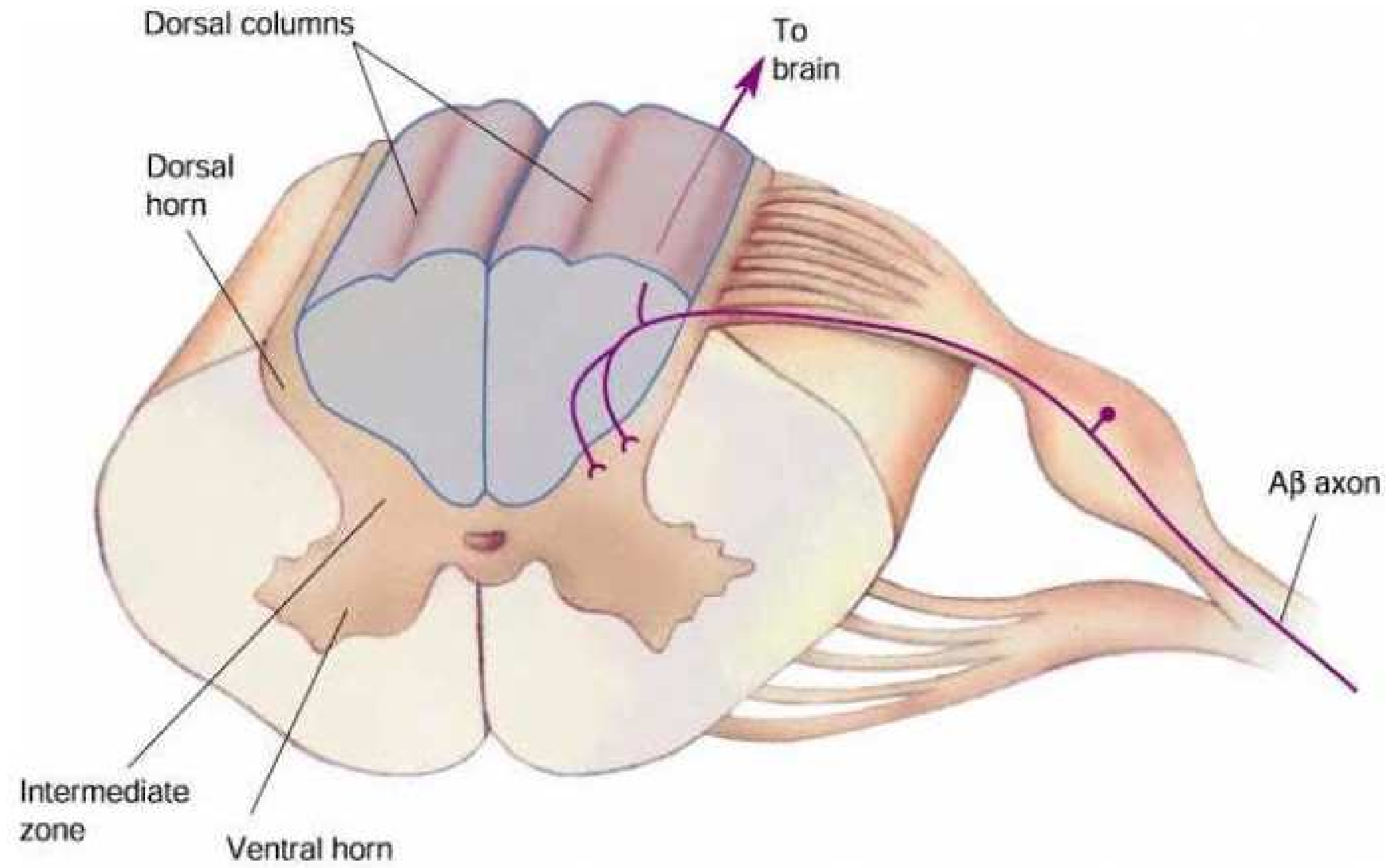
Pathways for sensory information

- The cell somas of mechanosensory axons are located in the dorsal root ganglion (DRG). One on each side of the spinal cord, one for each segmental spinal nerve
- DRG neurons called first-order because they initiate the sensory process
- All sensory axons cross the midline once
- All map to primary somatic sensory cortex, located in the postcentral gyrus
- Mechanoreceptors and proprioception receptors use the dorsal-column-medial lemniscus pathway to get to brain
- Pain and temperature use spinothalamic (anterolateral pathway)

Dorsal column-medial lemniscus system

- Dorsal root ganglion neurons– first order, initiate process
- Contains info from mechanoreceptors concerned with tactile discrimination or proprioception
- Upon entering spinal cord, axons bifurcate into ascending and descending branches, which in turn send out collateral branches to several spinal segments
- Some branches go to ventral horn of the cord and synapse on neurons that are part of the reflex system

Dorsal column-medial lemniscus system

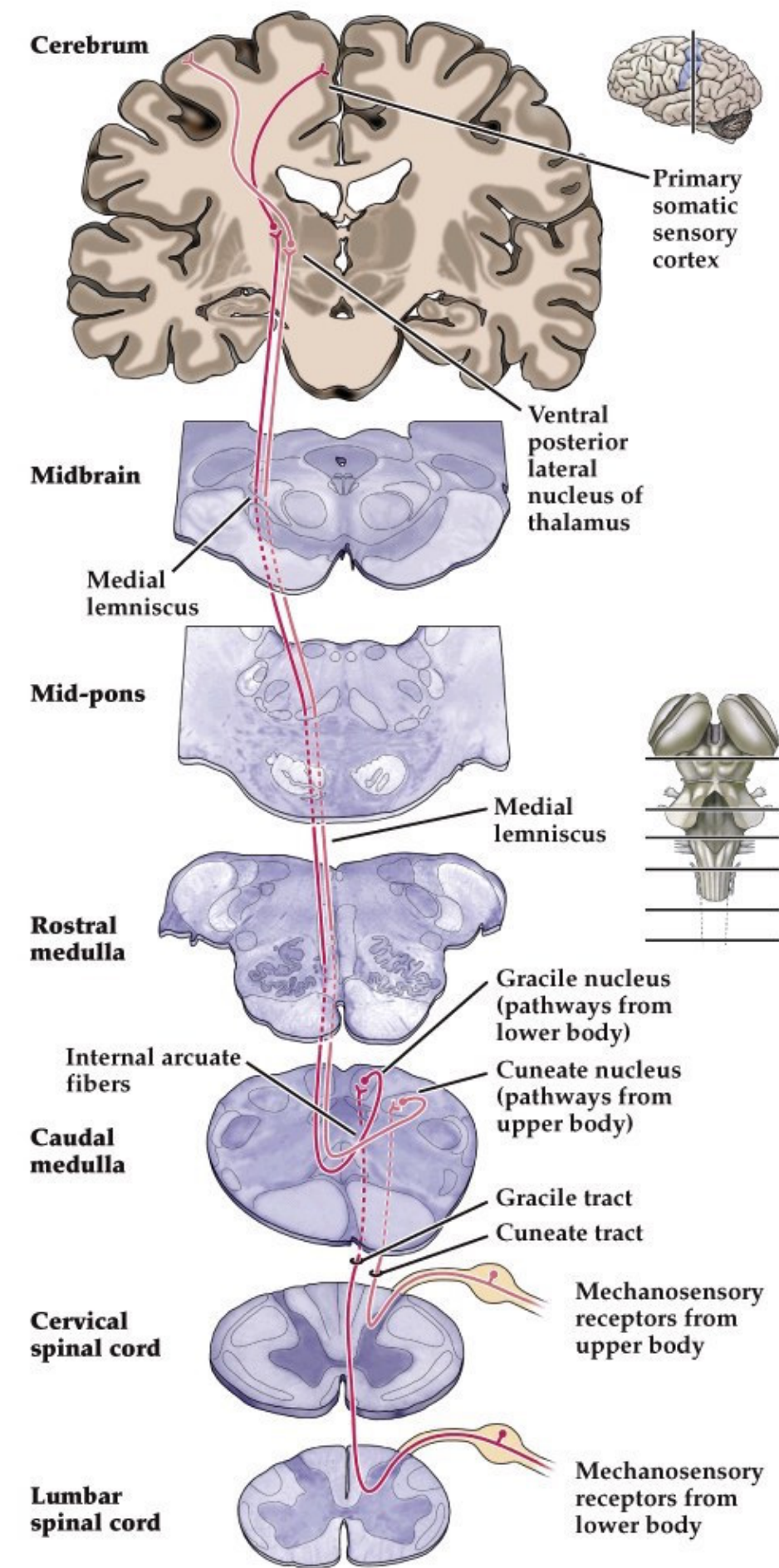


Second order mechanosensory neurons

- The major branches of dorsal root ganglion neurons are ascending and go up the dorsal columns of the spinal cord ipsilaterally
- They terminate in the gracile and cuneate nuclei (dorsal column nuclei) in the caudal (posterior) medulla
- Axons are organized such that lower limbs are mapped medially (gracile nucleus) and the upper limbs, trunk, and neck in the cuneate nucleus
- Axons from both nuclei cross the midline in the medulla and send projections to the somatic sensory portion of the thalamus, the ventral posterior lateral nucleus (VPL). Cuneate axons terminate in medial VPL, gracile projections terminate in lateral VPL

Mechanosensory pathways (body)

Upper and lower body use slightly different pathways. ****Cross in the medulla****



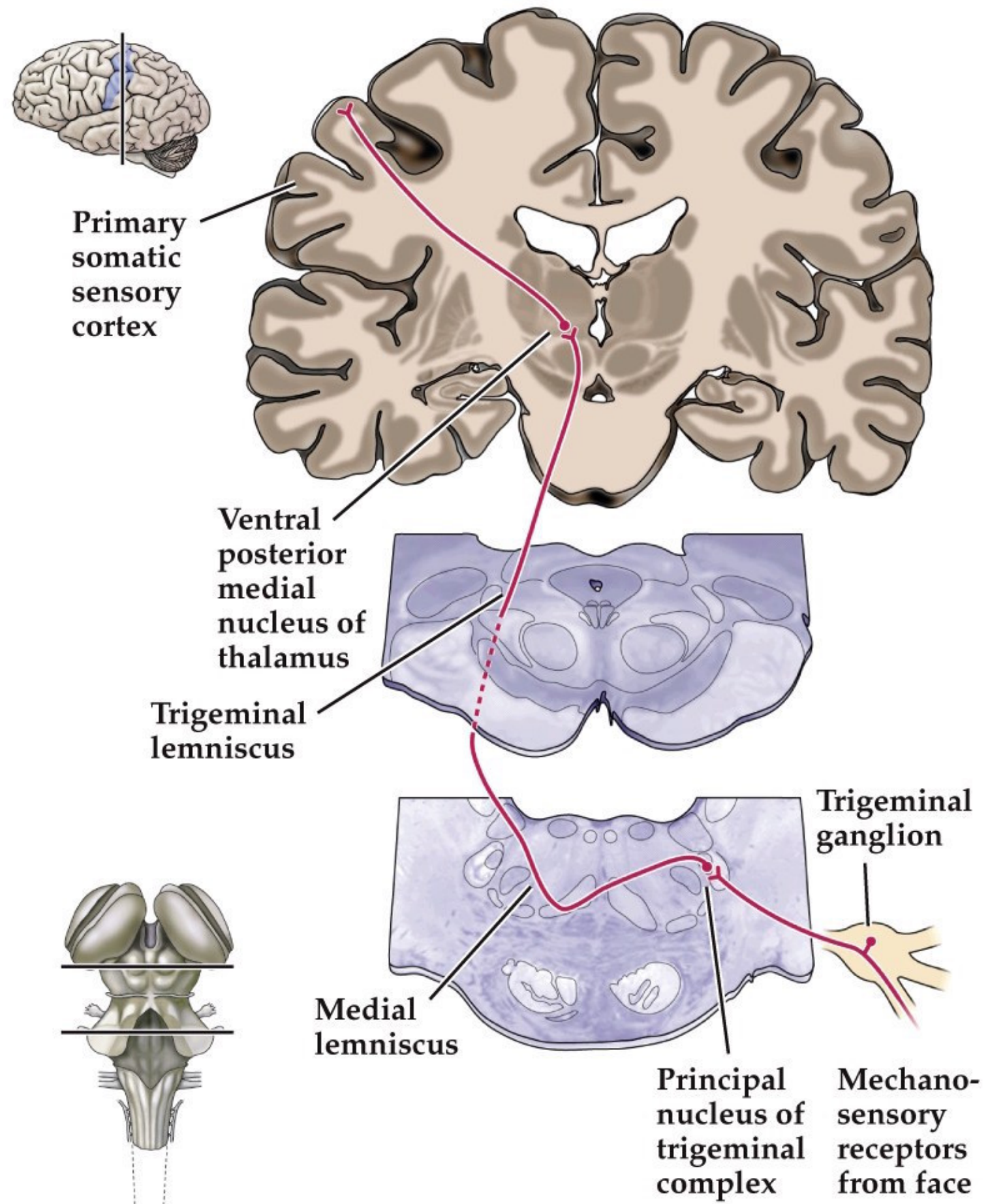
Neuroscience 5e Fig. 9.8

Trigeminal tract

- Information about the face takes a different route to the thalamus
- Trigeminal nerve (cranial nerve V, three subdivisions: ophthalmic, maxillary, and mandibular)
- Enters the brainstem at the level of the pons and terminates in the trigeminal brainstem complex. This complex has two main components, the principal nucleus (mechanosensory stimuli) and the spinal nucleus (pain and temp)
- Crosses midline in the pons and ascends to thalamus

Trigeminal pathway (face)

Info from head and face. ****Crosses in pons midbrain****



Neuroscience 5e Fig. 9.8

The somatic sensory components of the thalamus

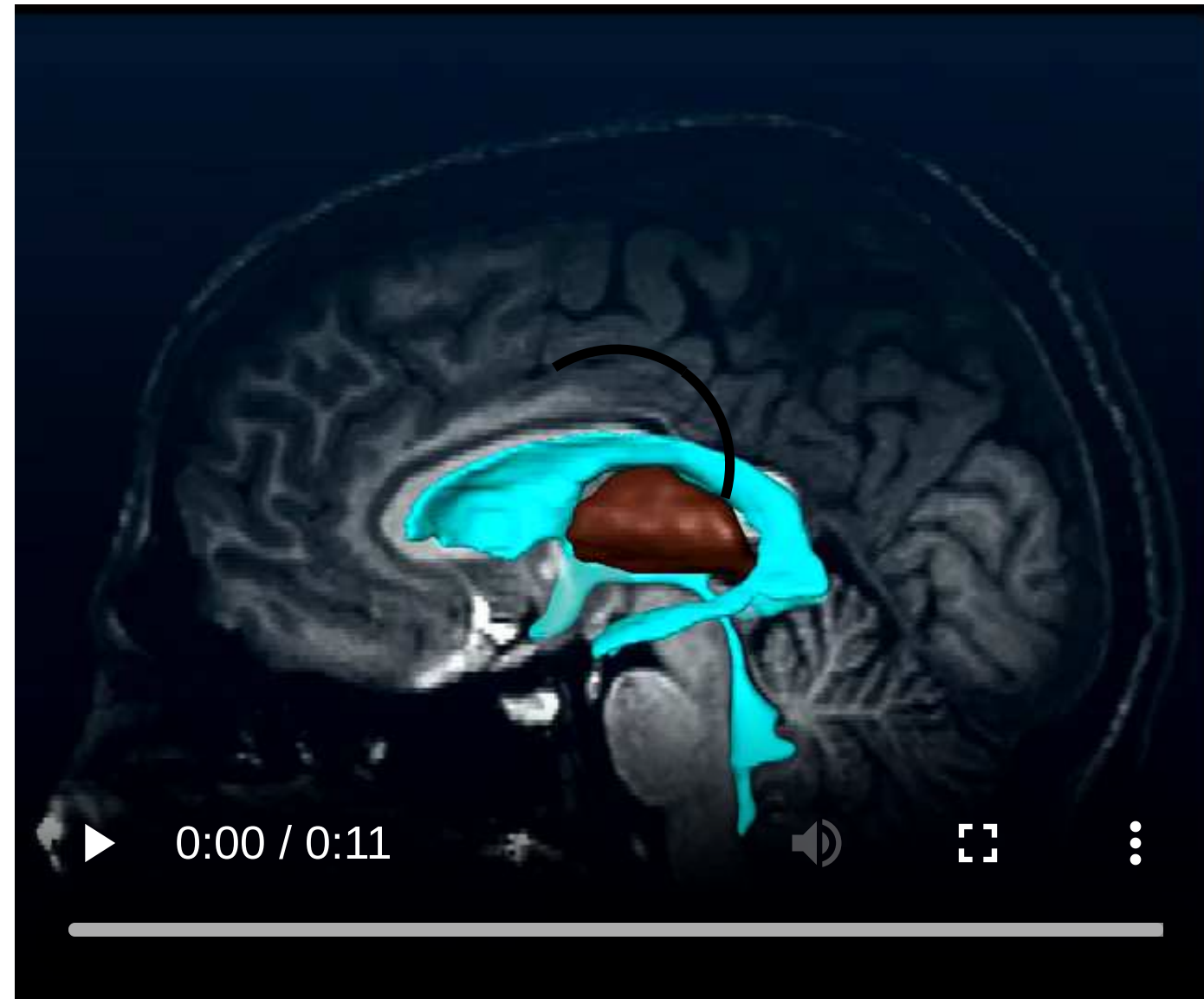
- Ventral posterior complex (VPC)–
 - Ventral posterior lateral nucleus (VPL) receives projections from the medial lemniscus carrying all somatic sensory information from the body and posterior head
 - Ventral posterior medial nucleus (VPM) receives axons from the trigeminal info from the face
- VPC contains a complete representation of the body

The thalamus is located in the middle of the brain...

red nucleus is part of midbrain, without a corticospinal tract it controls gait. Baby crawling controlled by red nucleus. Arm swinging while walking

Thalamus– gateway to the cerebral cortex

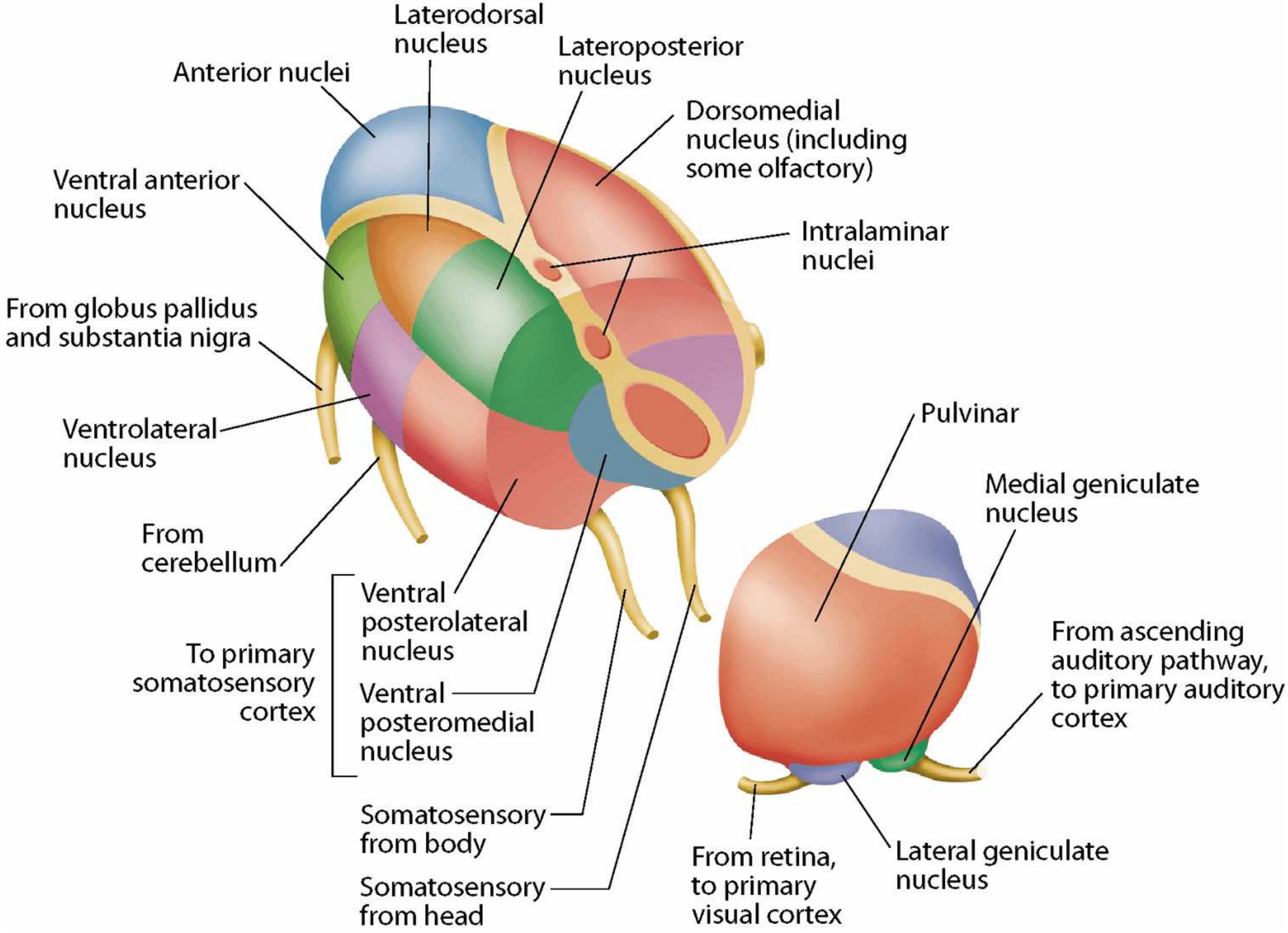
Thalamus (brown), ventricles (blue)



[C. Krebs CC BY-NC-SA, Univ. British Columbia](http://www.neuroanatomy.ca/3D_files/3D_index.html?id=1)

Fiber stain

Thalamus subdivisions



Neuroscience 3/4e (5e Box A)

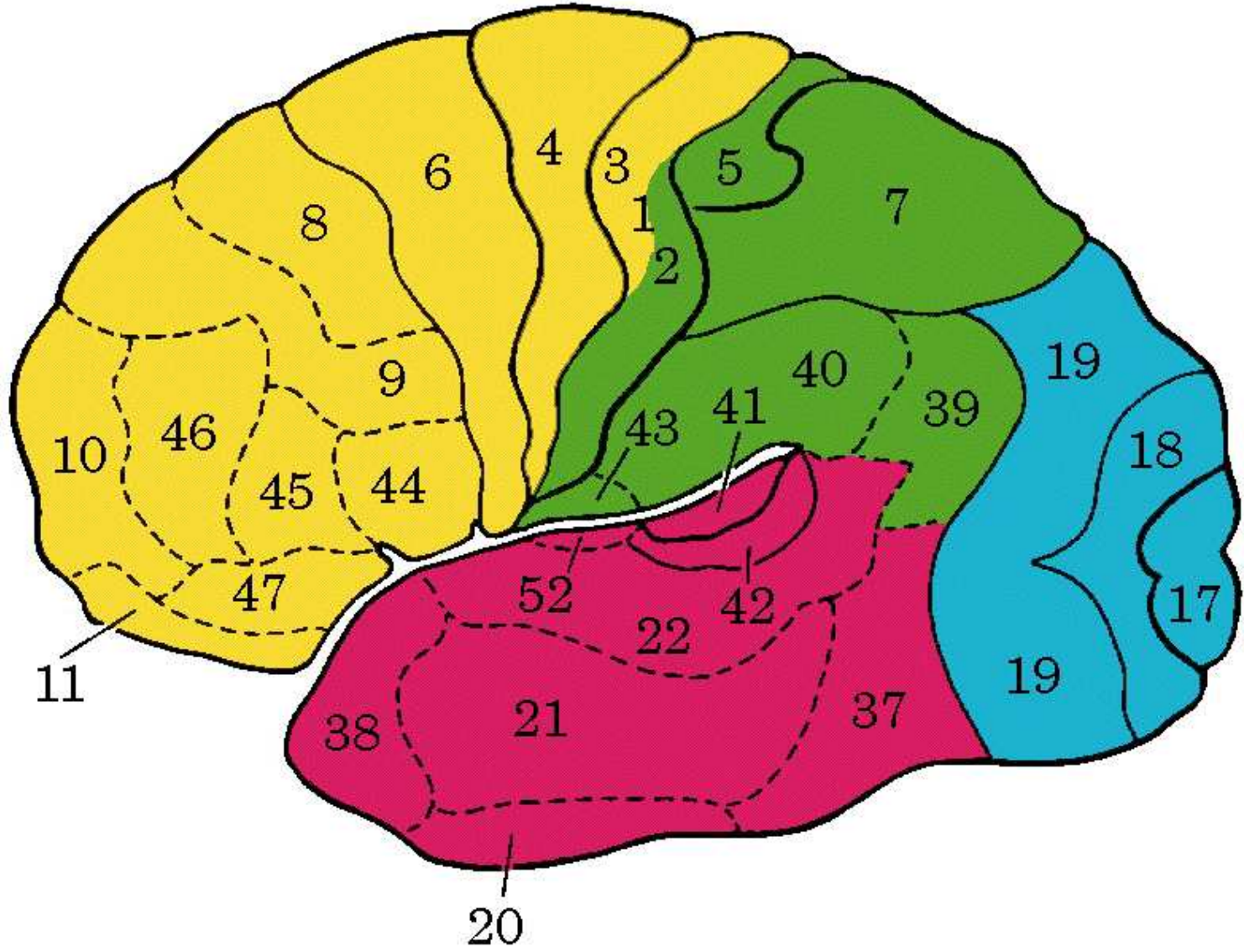
Speaker notes

...and is the gateway for routing information into the cerebral cortex. It contains a number of different nuclei and subdivision that take information from other brain regions including the brain stem and sends to appropriate primary sensory or higher order regions of the cerebral cortex.

Somatic sensory cortex

- All axons from ventral posterior complex project primarily to layer IV of the somatic sensory cortex
- Located in parietal lobe, post-central gyrus
- Divided into regions, Brodmann's areas 3a, 3b, 1 and 2 that together comprise the primary somatosensory cortex, SI

Brodmann areas



Brodmann 1909 color

Speaker notes

Note areas 4 (primary motor cortex), 1,2,3 (primary somatosensory cortex), area 17 (primary visual cortex), area 18 (secondary visual cortex), area 41,42 (primary auditory cortex, also part of 22)

Comparative localization teachings of the cerebral cortex in their principles, illustrated on the basis of Zellenbaues. Leipzig, Johann Ambrosius Barth Verlag, 1909 . 2nd edition, 1925. English translation by Laurence J. Garey: Localisation in the Cerebral Cortex by Korbinian Brodmann. Smith-Gordon, 1994; new impression: Imperial College Press., 1999

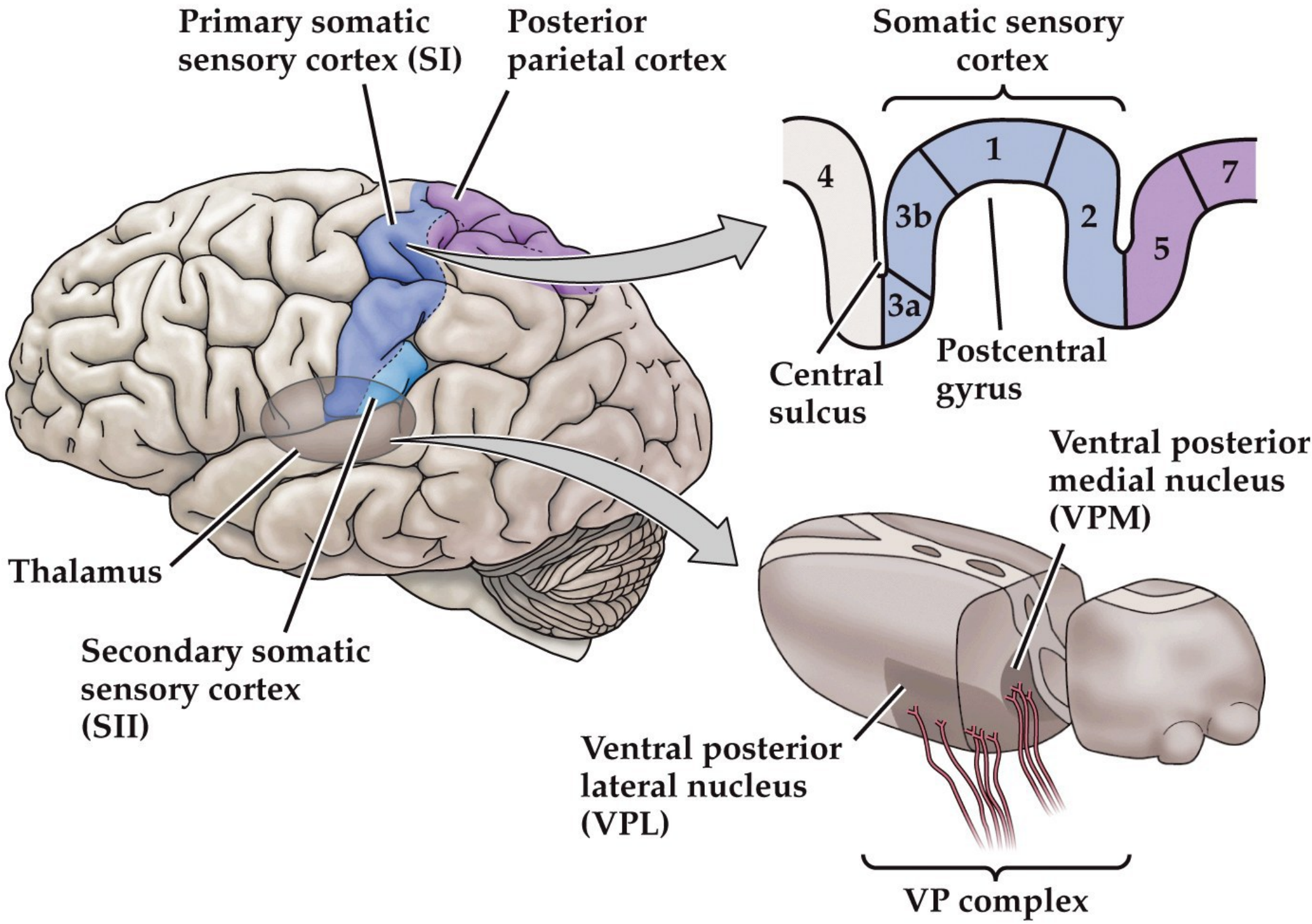
- area 44,45 Broca's areas
- area 39,40,22 wernicke's areas
- area 43 gustatory cortex
- area 22 superior temporal gyrus

Somatic sensory portions of the thalamus and cortical targets

Speaker notes

Cross section view shows that there are really 4 subdivisions of primary somatosensory cortex

In VP complex, Upper body medial, Lower body lateral

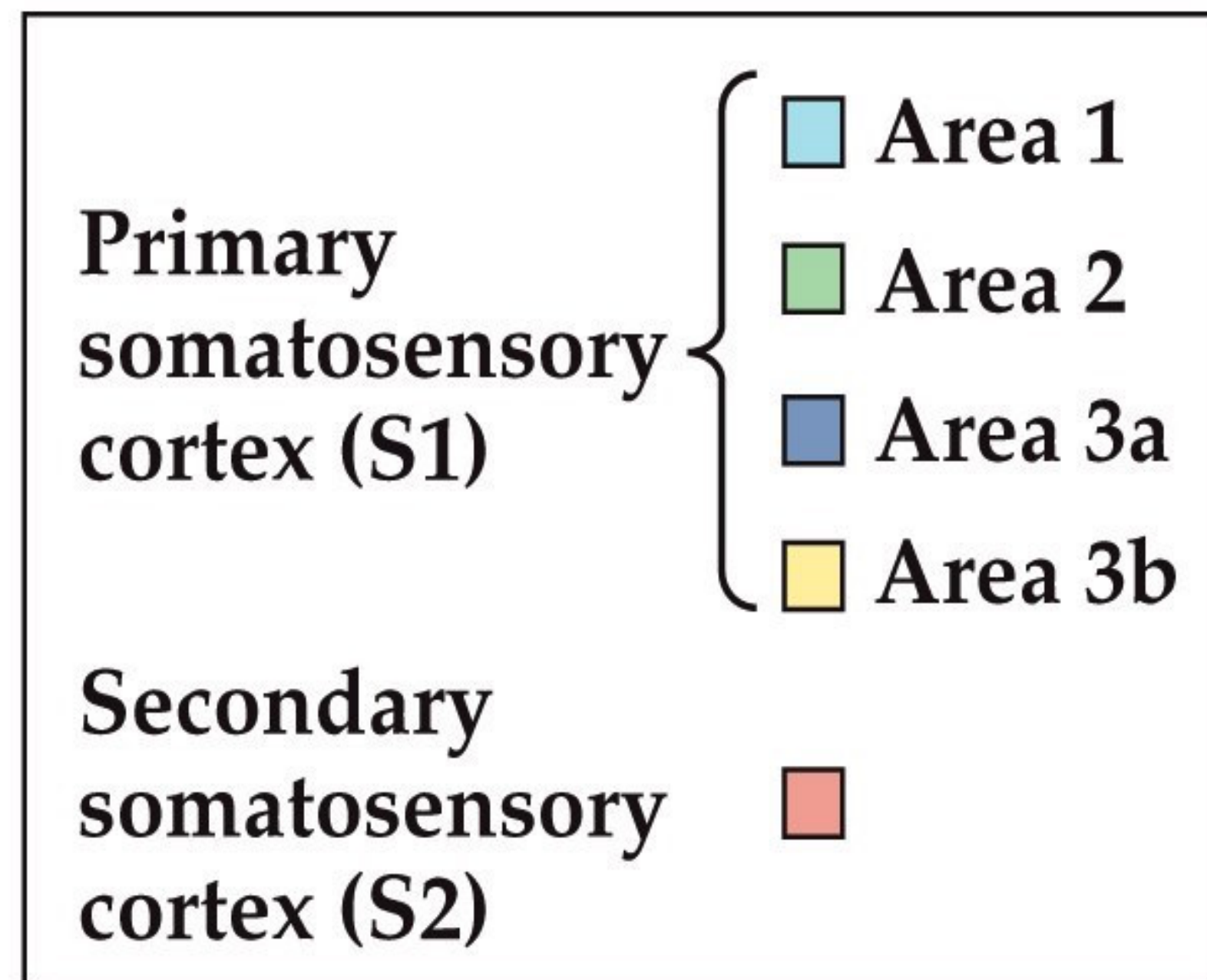
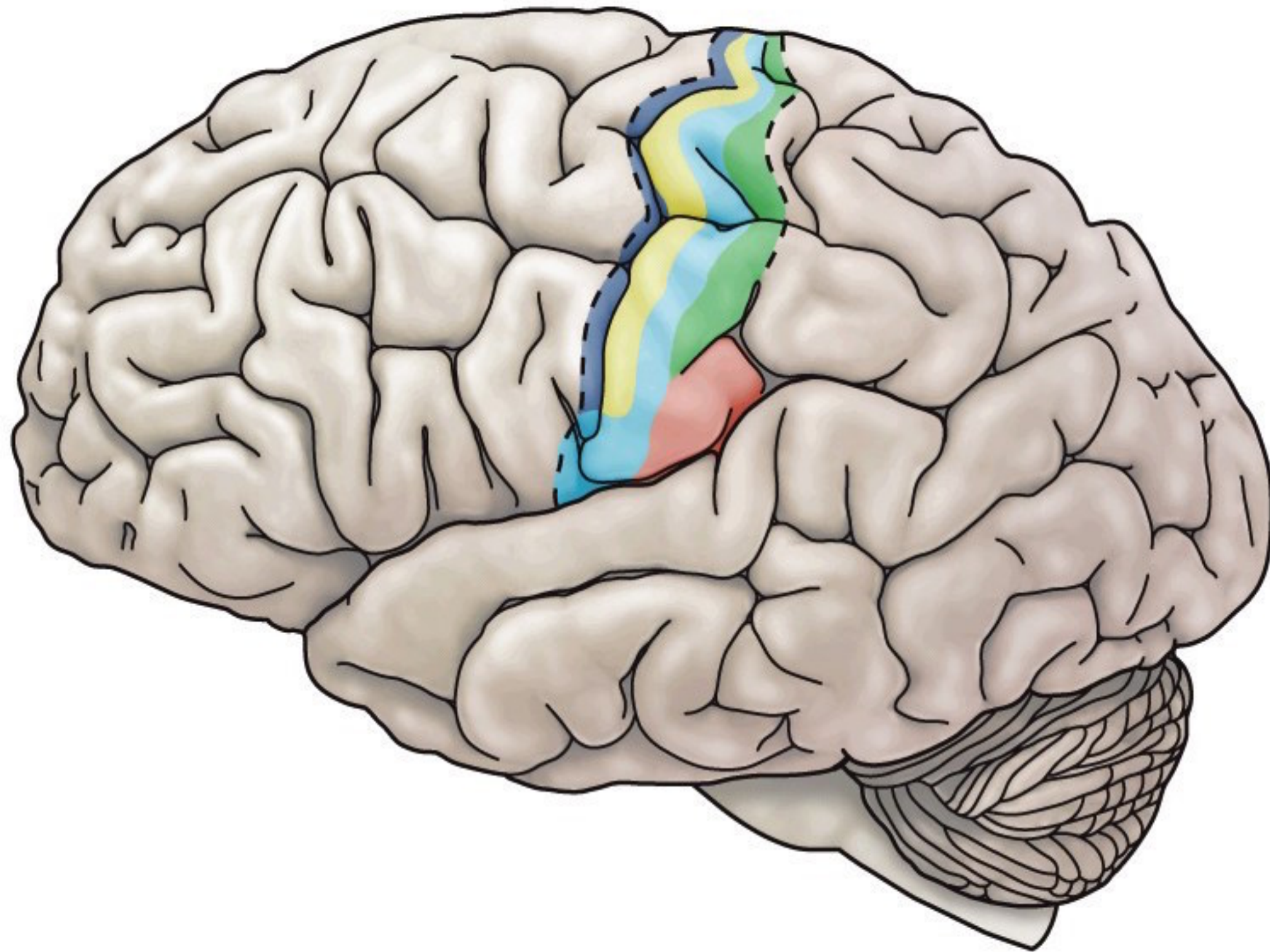


Neuroscience 5e Fig. 9.10

Receptive fields of somatosensory cortical neurons

- Area 3b and 1– cutaneous stimuli
- 3a– proprioceptive stimuli
- 2– tactile and proprioceptive stimuli
- SI is organized in columns, by receptive field, and modality. Stick an electrode vertically, all neurons share same region of body

Somatotopic order in the human primary somatosensory cortex

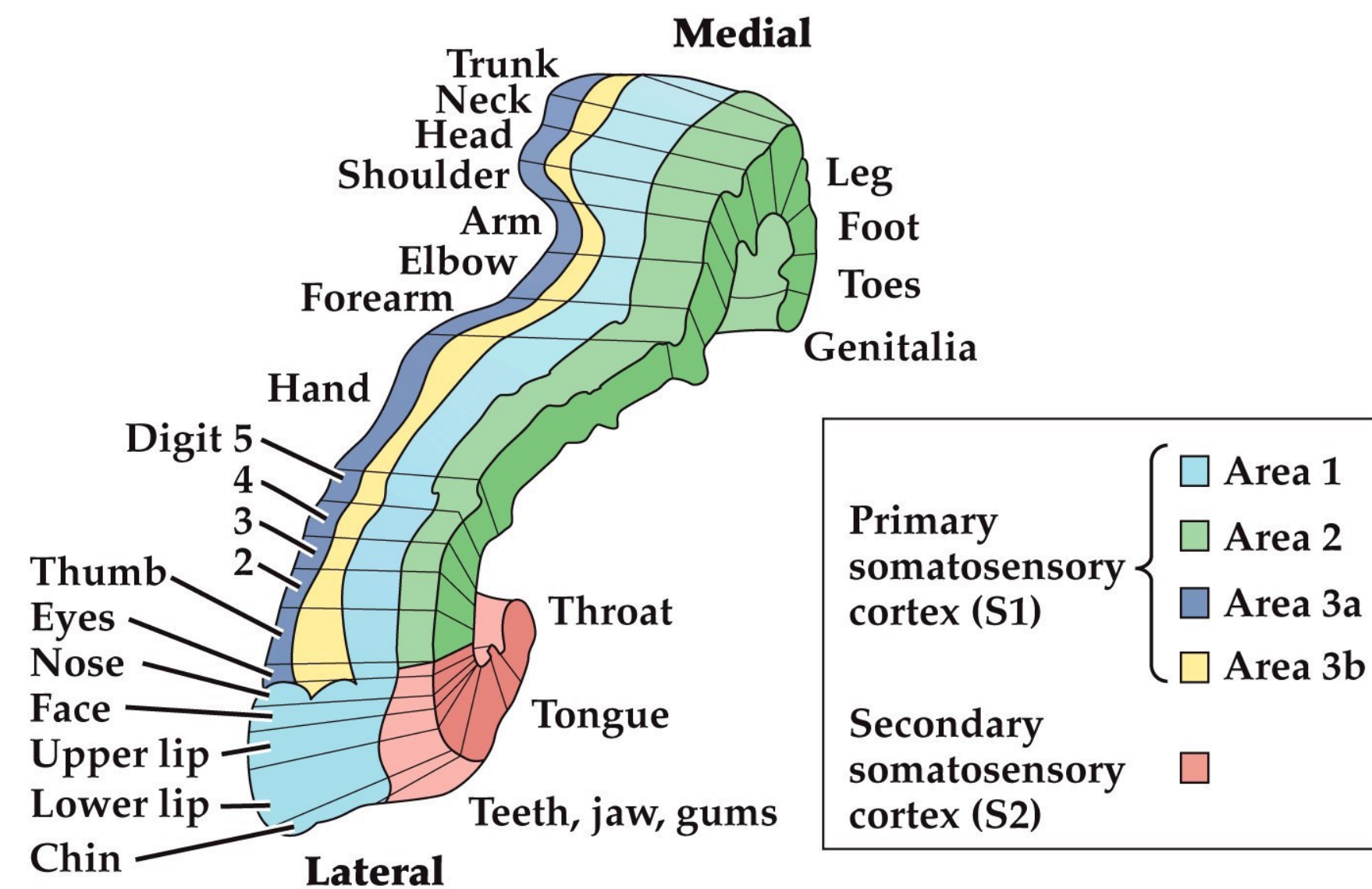


More cortical space for body areas with higher somatic receptor density

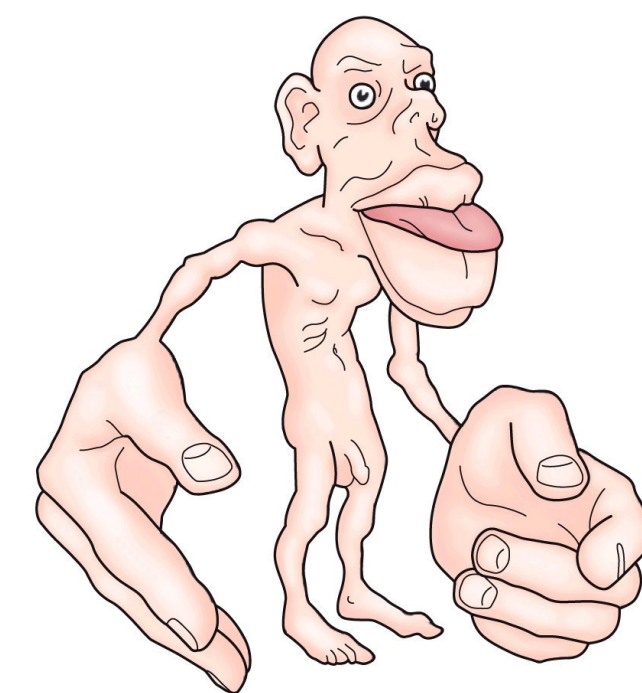
topographic
: the arrangement or accurate representation of the physical features of an area

Somatotopic order in the primary somatosensory cortex

- somatotopy– topographic representation of the body surface
- areas of high receptor density get more cortical space



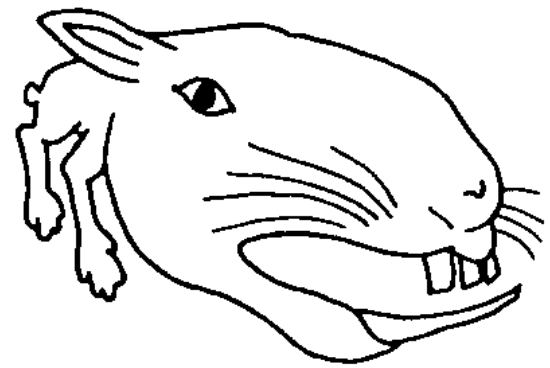
Neuroscience 5e Fig. 9.11



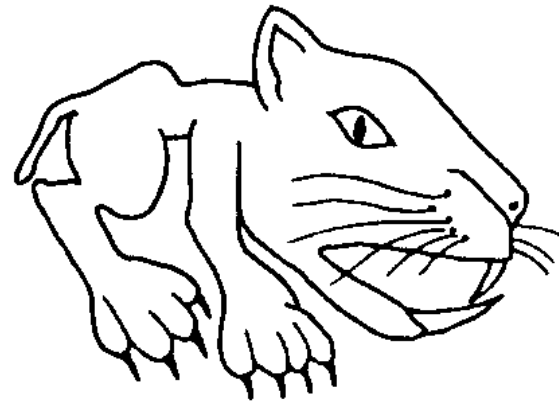
Neuroscience 5e Fig. 9.11

The 'homunculus' reflects sensory receptor density

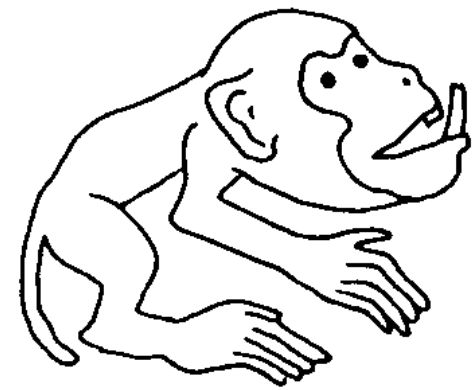
Rabbit



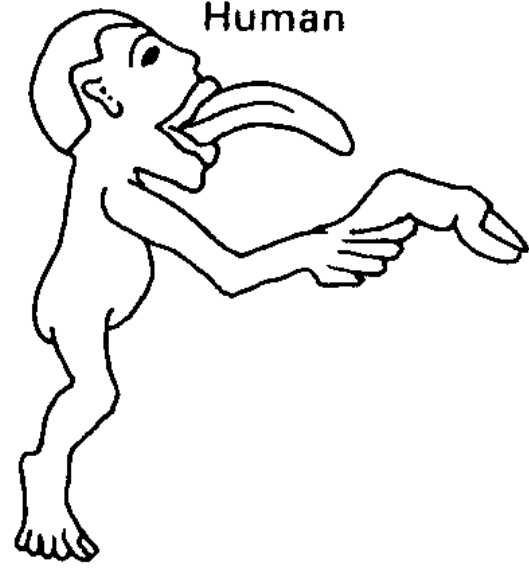
Cat



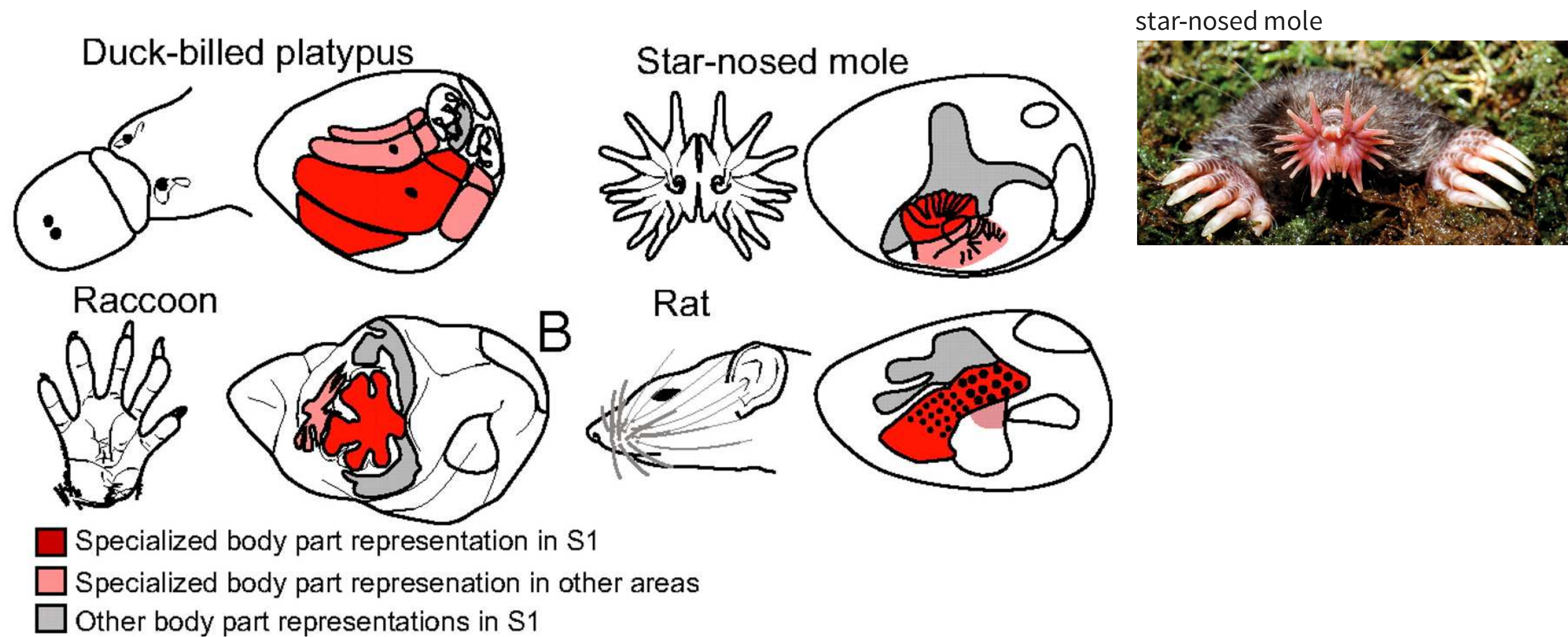
Monkey



Human



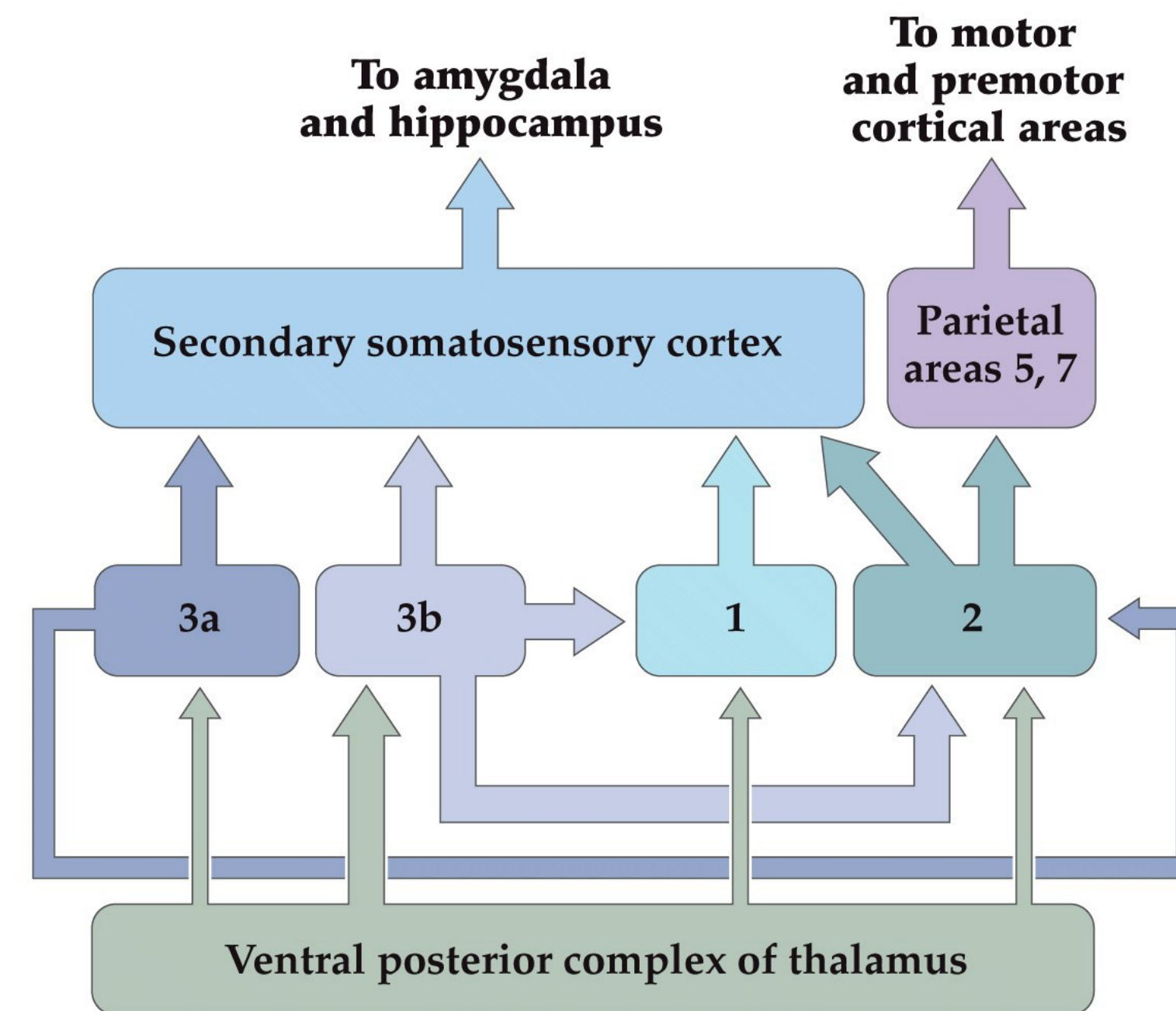
Magnified cortical representations of sensory apparatus



Krubitzer PNAS 2012 Fig. 3

Higher order processing

- SI sends out projections to other areas of cortex
- SII, adjacent to SI. Receives info from all 4 SI areas and sends it to amygdala and hippocampus. Plays roles in fear conditioning and tactile learning and memory



Neuroscience 5e Fig. 9.12