Bi/CNS/NB 150: Neuroscience

November 11, 2015

SOMATOSENSORY SYSTEM

Ralph Adolphs

Menu for today

Touch

- -peripheral
- -central
- -plasticity

Pain

Sherrington (1948): senses classified as

--teloreceptive (vision, hearing)

--proprioceptive (limb position)

--exteroceptive (touch)

--chemoreceptive (smell and taste)

--interoceptive (visceral: the sense of the physiological condition of the entire body)

What is feeling?

Similarities between audition, vision, and touch

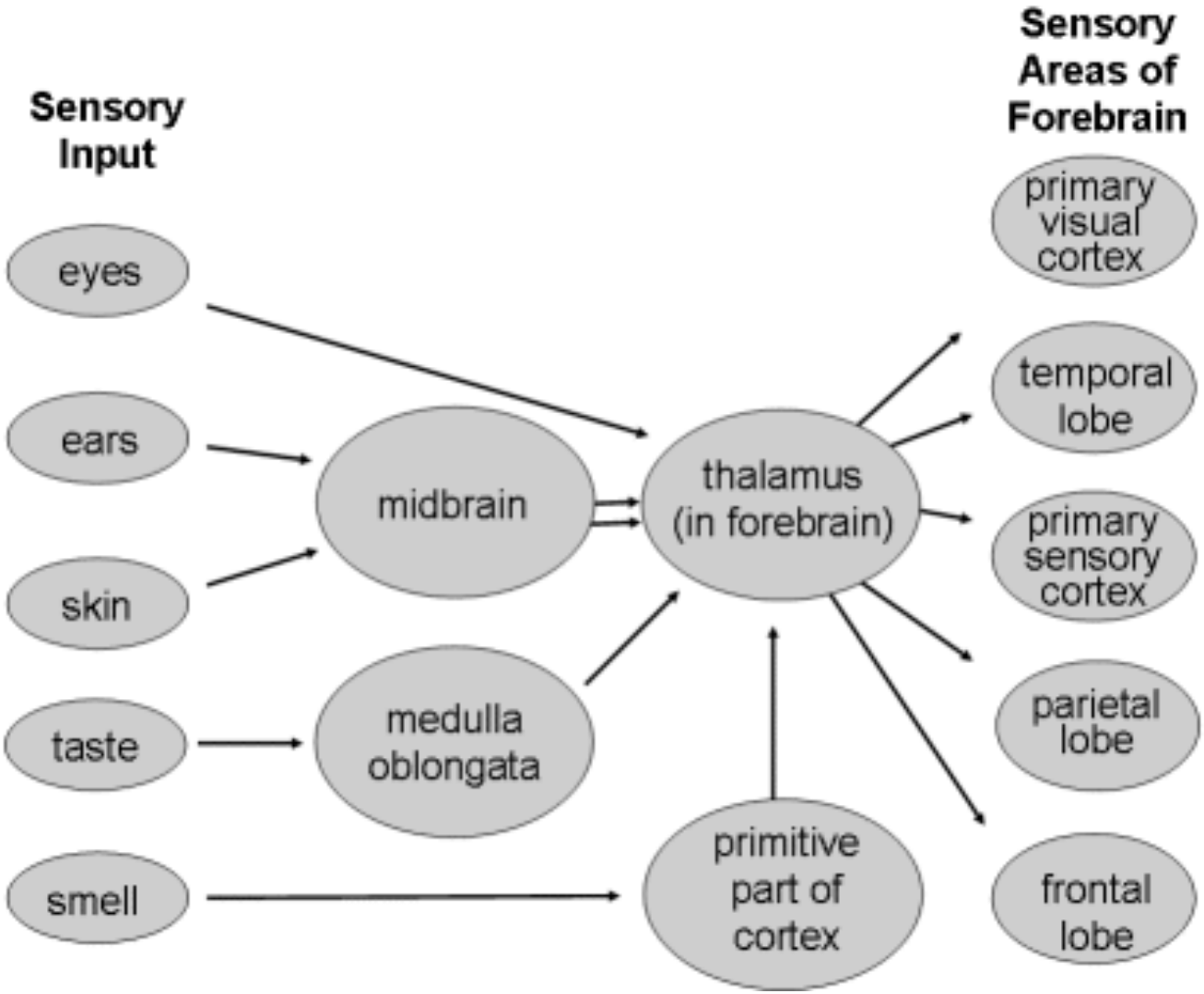
Processing streams
Topographic maps
Distortion/magnification
Perception is inferential
Perception makes comparisons
Can be driven in the absence of sensory input
Plastic periods in development
Important role in social communication

Differences between audition and vision

	Audition	Vision
Transduction	Fast	Slow
Temporal Acuity	High	Low
Spatial Acuity	Low	High
Feedback	To cochlea	not to retina
Active sense	Somewhat	Very
Specializations	Language	Faces
Receptor Numb.	16k	100M

Differences between audition, vision, somatosens

	Audition	Vision	Somatosens
Transduction	Fast	Slow	Varies
Temporal Acuity	High	Low	Low-medium
Spatial Acuity	Low	High	Medium-high
Feedback	To cochlea	not to retina	to spinal cord
Active sense	Somewhat	Very	Moderate
Specializations	Language	Faces	Stereognosis, social
Receptor Numb.	16k	100M	maybe 100k?


Sensory Input
eyes
ears
skin
taste
smell
midbrain
medulla oblongata
thalamus (in forebrain)
primitive part of cortex
Sensory Areas of Forebrain
primary visual cortex
temporal lobe
primary sensory cortex
parietal lobe
frontal lobe

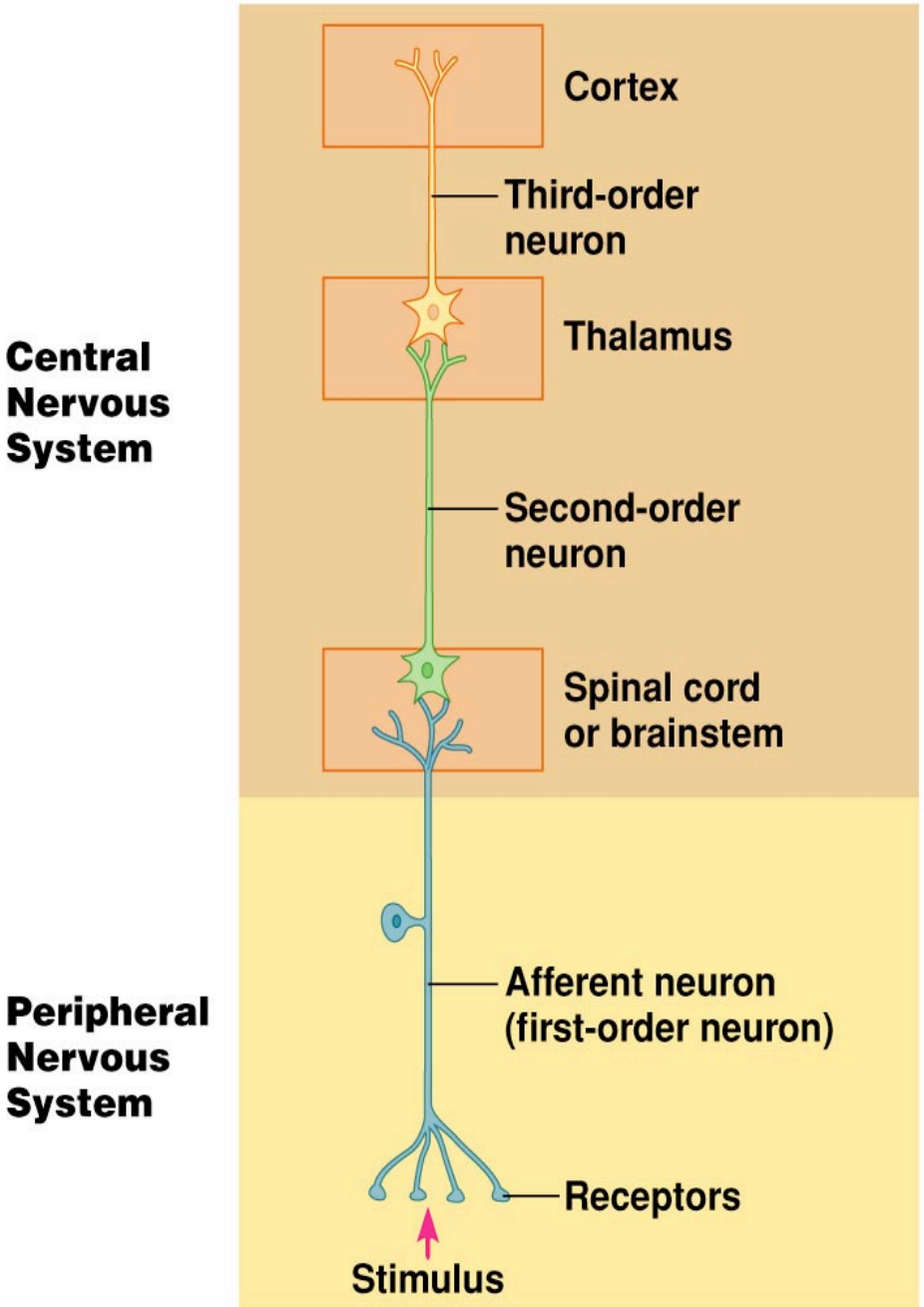
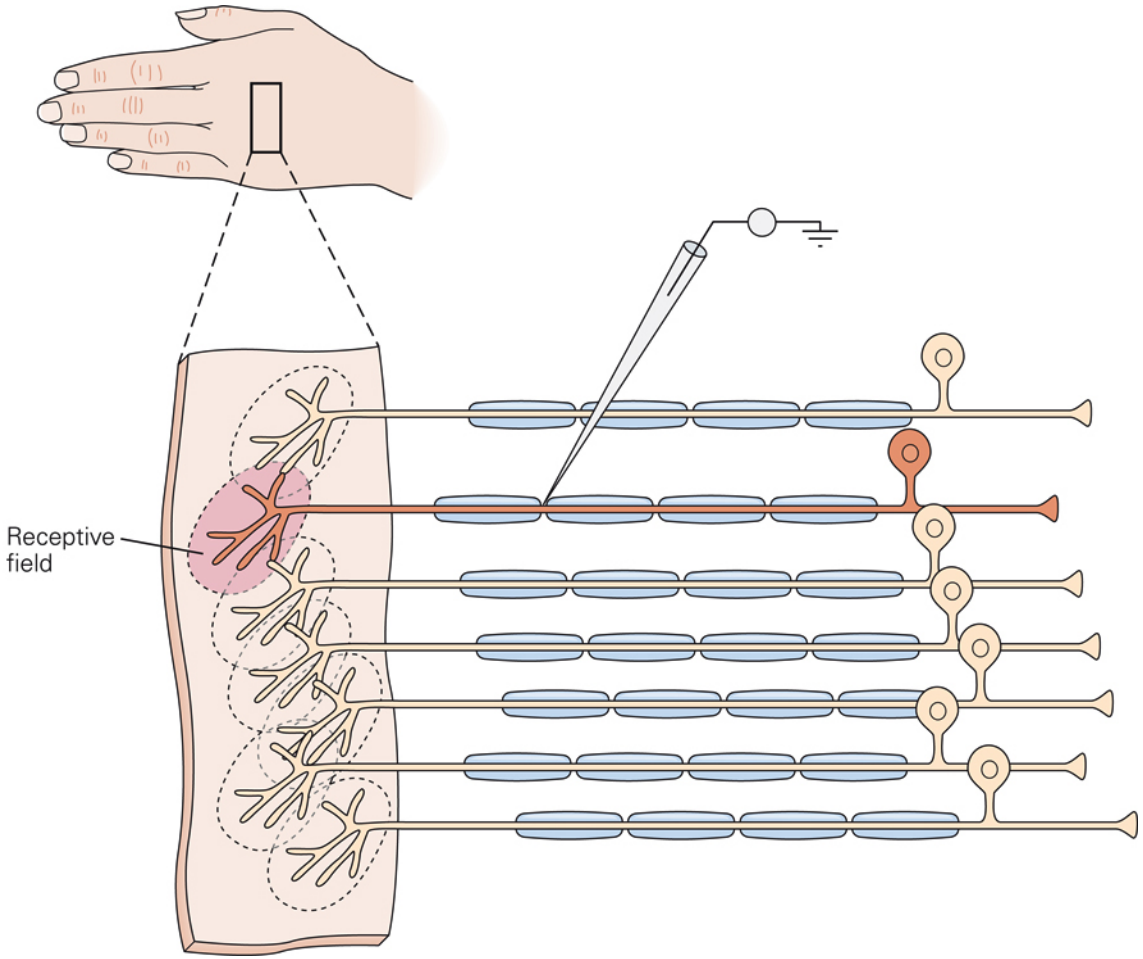


Figure 21–9 The receptive field of a sensory neuron is the spatial domain in the sense organ where stimulation excites or inhibits the neuron. The receptive field of a touch-sensitive neuron denotes the region of skin where gentle tactile stimuli evoke action potentials in that neuron. It encompasses all of the receptive endings and terminal branches of the sensory nerve fiber. If the fiber is stimulated electrically with a microelectrode, the subject experiences touch localized to the receptive field on the skin. The area from which the sensation arises is called the *perceptive field*. A patch of skin contains many overlapping receptive fields, allowing sensations to shift smoothly from one sensory neuron to the next in a continuous sweep. The axon terminals of sensory neurons in the central nervous system are arranged somatotopically, providing an orderly map of the innervated region of the body.



Neural code:

-Rate
-Timing
-Place
-”labelled lines”

Coding

Quality: place, labeled line
(pain is NOT just intense touch)

Intensity: rate code
-static (tonic; free nerve endings)
-dynamic: adaptation (phasic; Pacinian corpuscles)

Sub-modalities:

-discriminative touch
-proprioception (limb position, kinesthesia)
-pain (mechanical, thermal, polymodal)
-temperature

can add: interoception

Discriminative touch:

1. fine touch localization (varies over body)
2. 2-pt discrimination
3. vibration, flutter
4. stereognosis

Cutaneous and subcutaneous receptors

-extremely diverse, many channels

- 3 main groups:
  - -mechanoreceptors
  - -nociceptors
  - -thermoceptors

-Encapsulated and free endings

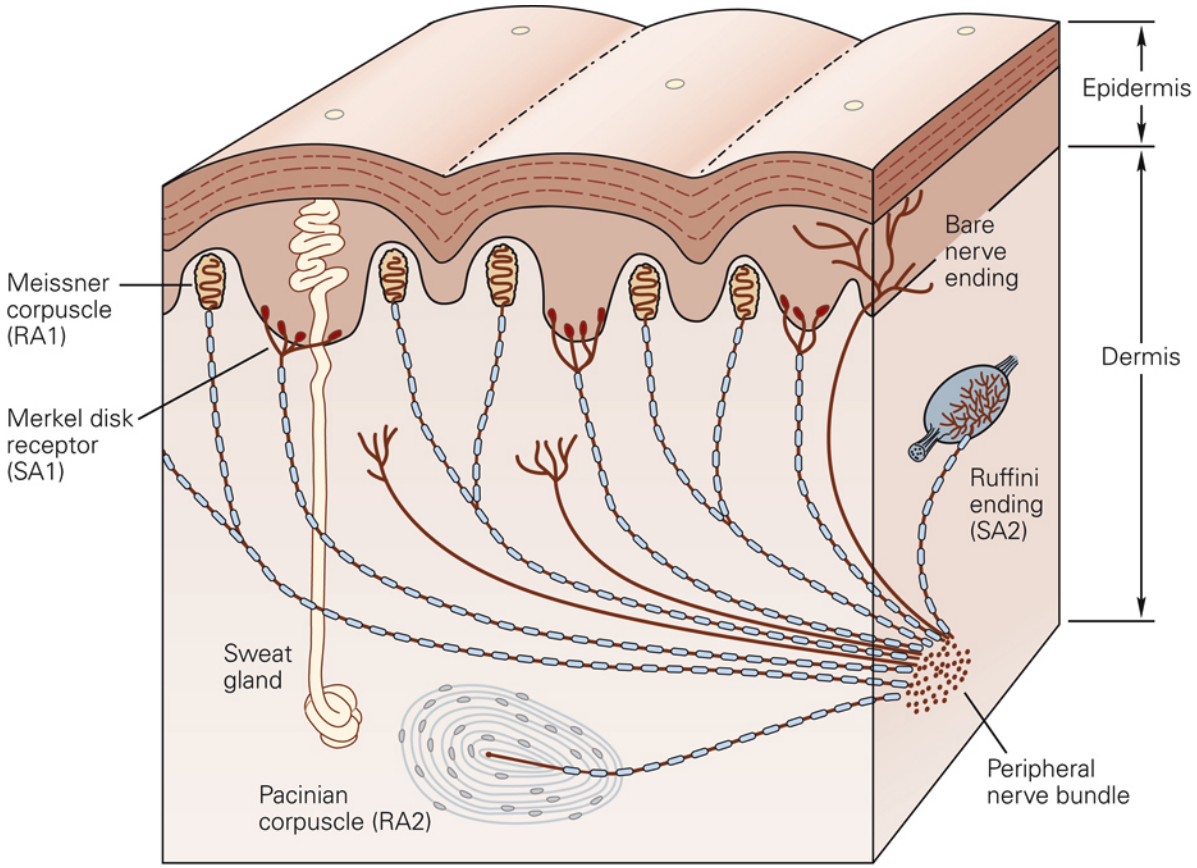


Figure 23–1 Four mechanoreceptors are responsible for the sense of touch. A cross section of the glabrous skin shows the principal receptors for touch. All of these receptors are innervated by large-diameter myelinated fibers. The Meissner corpuscles and Merkel cells lie in the superficial layers of the skin at the base of the epidermis, 0.5 to 1.0 mm below the skin surface. The Meissner corpuscles border the edges of each papillary ridge, whereas the Merkel cells form dense bands surrounding the sweat gland ducts along the center of the ridges. The RA1 and SA1 fibers that innervate these receptors branch at their terminals so that each fiber innervates several nearby receptor organs. The Pacinian and Ruffini corpuscles lie within the dermis (2–3 mm thick) and deeper tissues. The RA2 and SA2 fibers that innervate these receptors each innervate only one receptor organ. (**RA1**, rapidly adapting type 1; **RA2**, rapidly adapting type 2; **SA1**, slowly adapting type 1; **SA2**, slowly adapting type 2.)

Sensations Produced by Intraneural Microstimulation in Humans

receptor	sensation produced
FA I (Meissner's corpuscle)	tapping at 1Hz, flutter at 10Hz and vibration at 50Hz
FA II (Pacinian corpuscle)	tickle/vibration over 20 - 50Hz
SA I (Merkel's disk)	sustained pressure over 5 - 10Hz
SA II (Ruffini endings)	no sensation
A δ mechanical nociceptors	sharp pain
C polymodal receptors	dull, burning pain or itch
muscle nociceptor (group IV)	cramping pain

Temporal responses

Merkel receptor – slow (~1 Hz)

- pressure (top layers of skin)

Meissner corpuscle – medium fast (~10 Hz)

- flutter

Ruffini cylinder – fast (~ 100 Hz)

- stretching

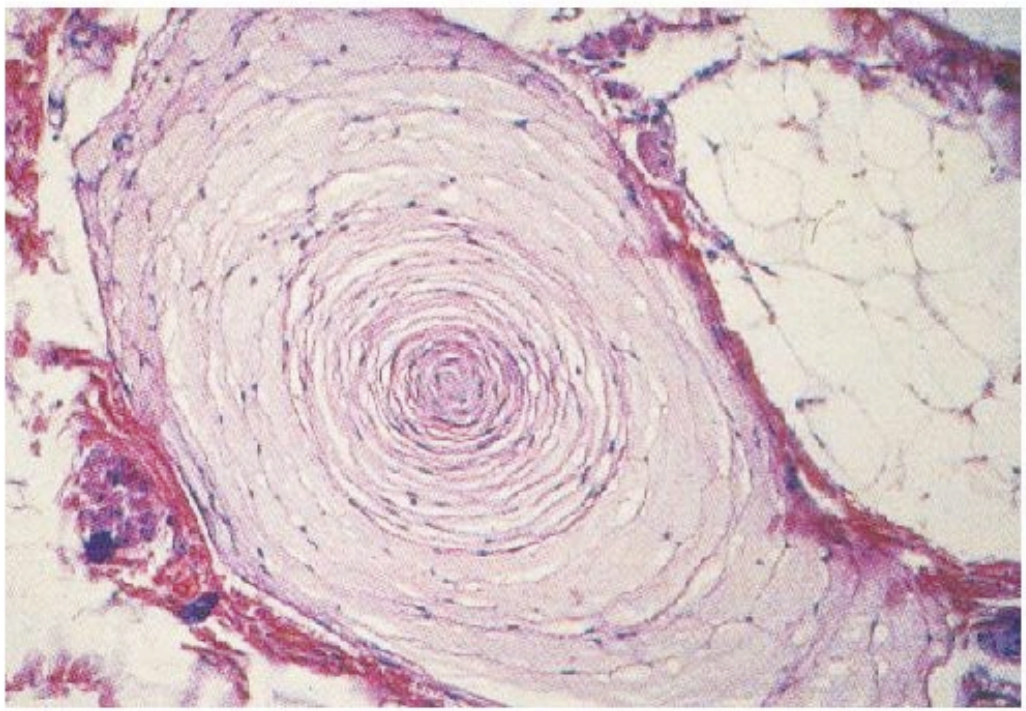
Pacinian corpuscle – very fast (~400 Hz)

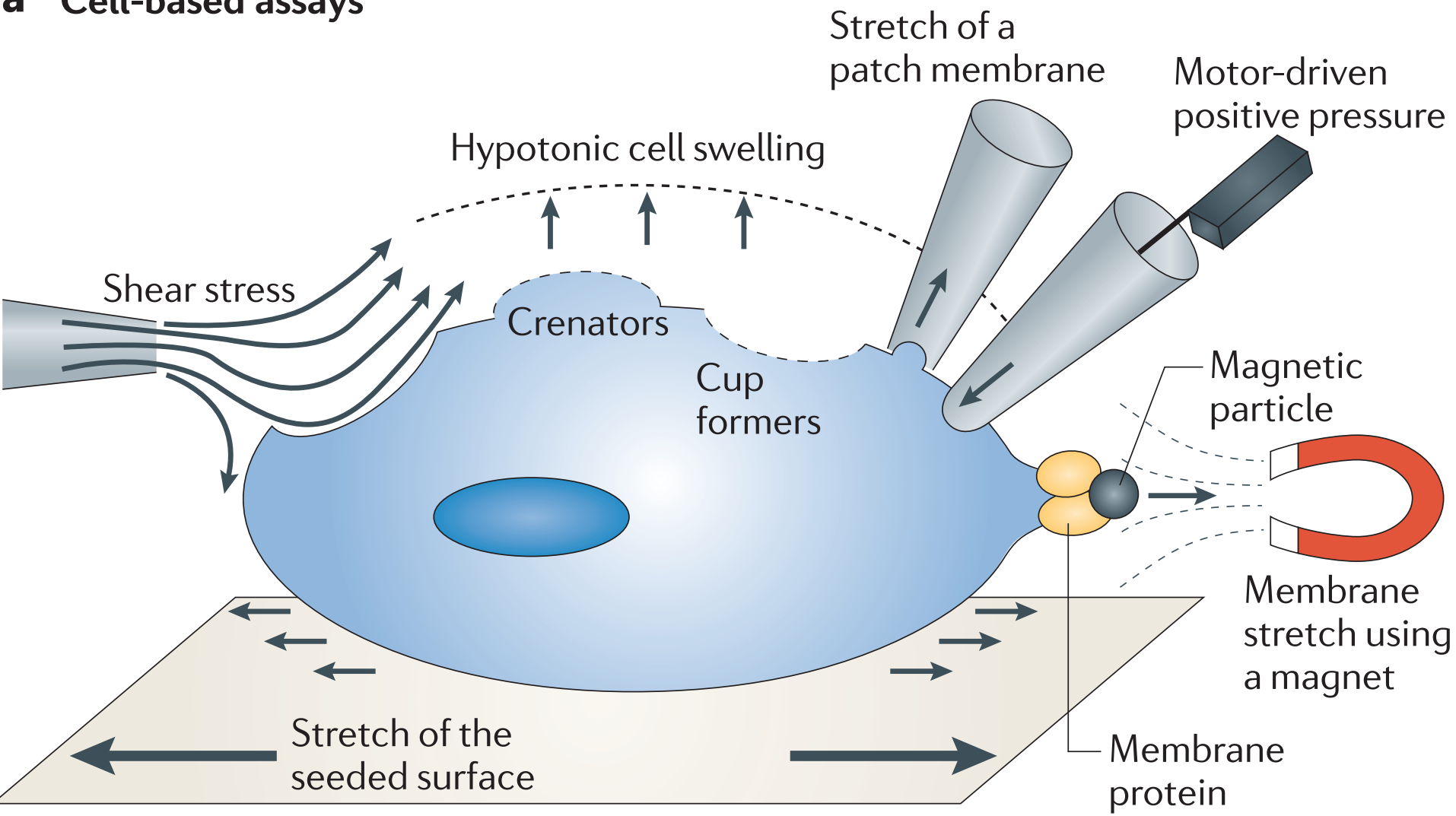
- vibration

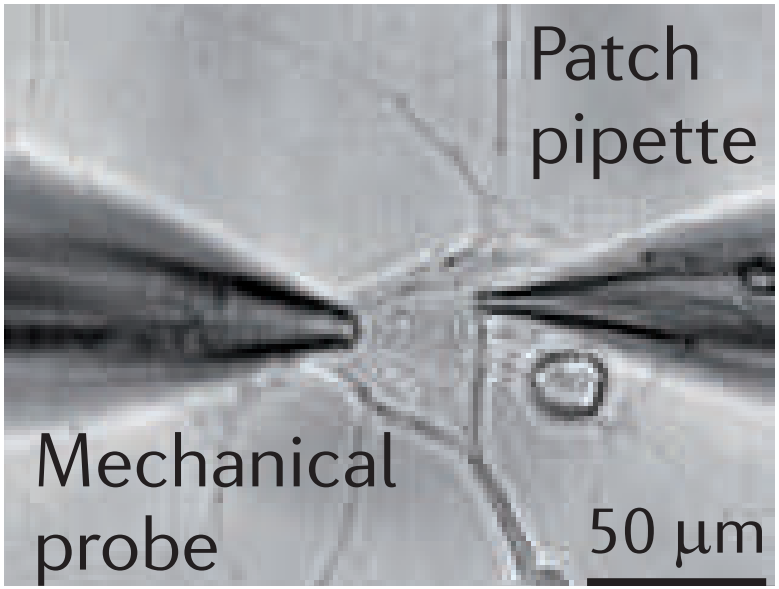
Pacinian corpuscle

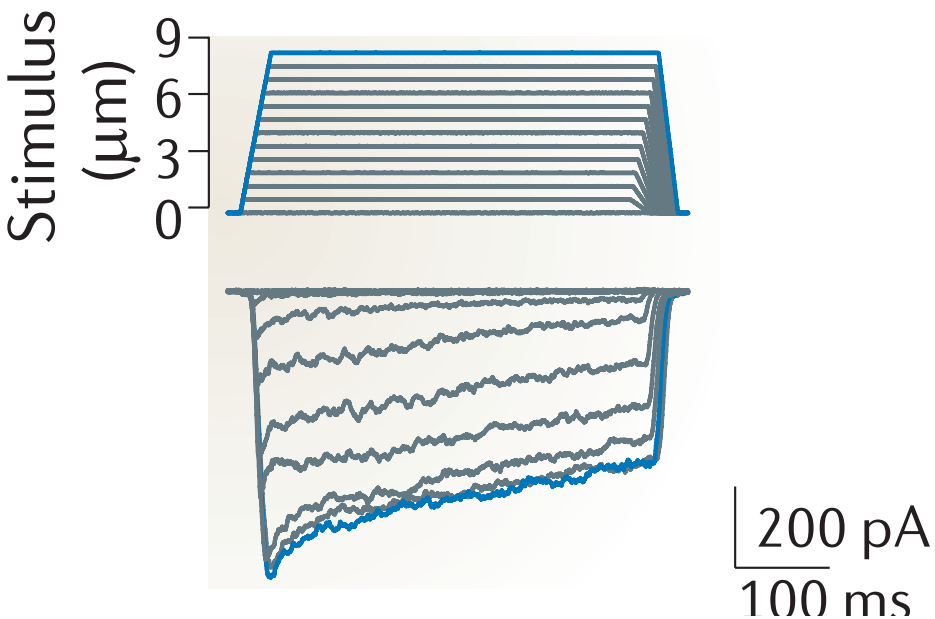
Large enough to see with the naked eye

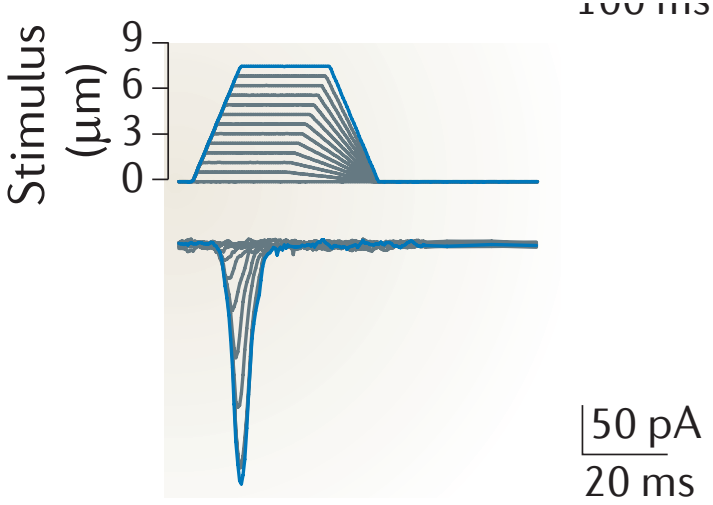
Layered like an onion

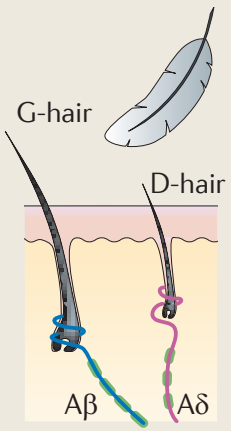
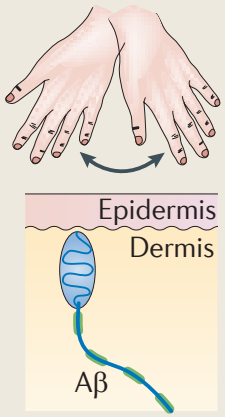
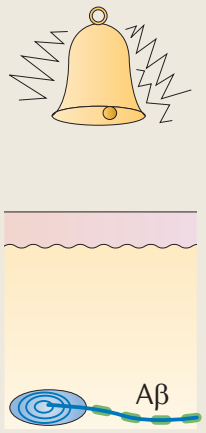
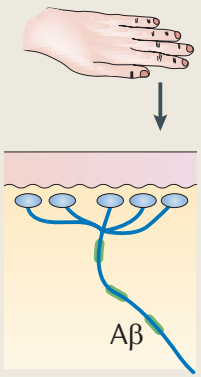
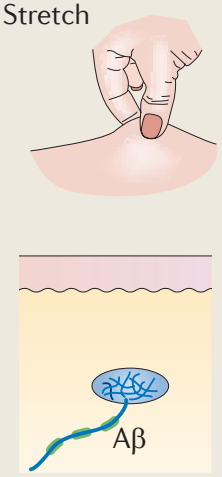
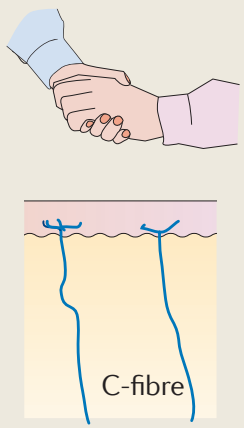
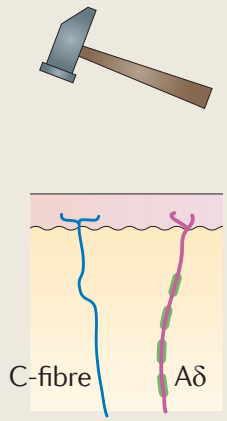


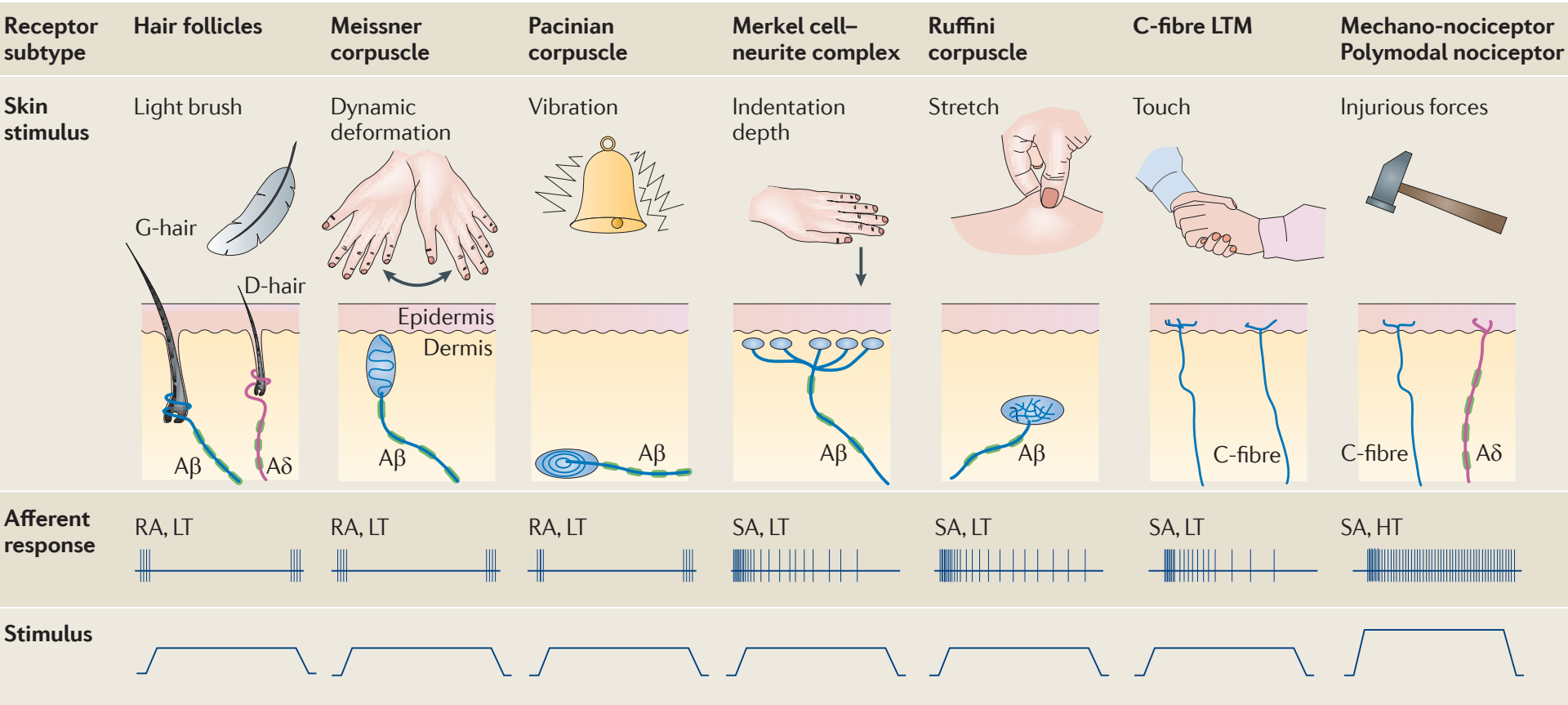

a Cell-based assays
Stretch of a patch membrane
Motor-driven positive pressure
Hypotonic cell swelling
Shear stress
Crenators
Cup formers
Magnetic particle
Membrane stretch using a magnet
Stretch of the seeded surface
Membrane protein


Patch
pipette
Mechanical
probe
50 µm

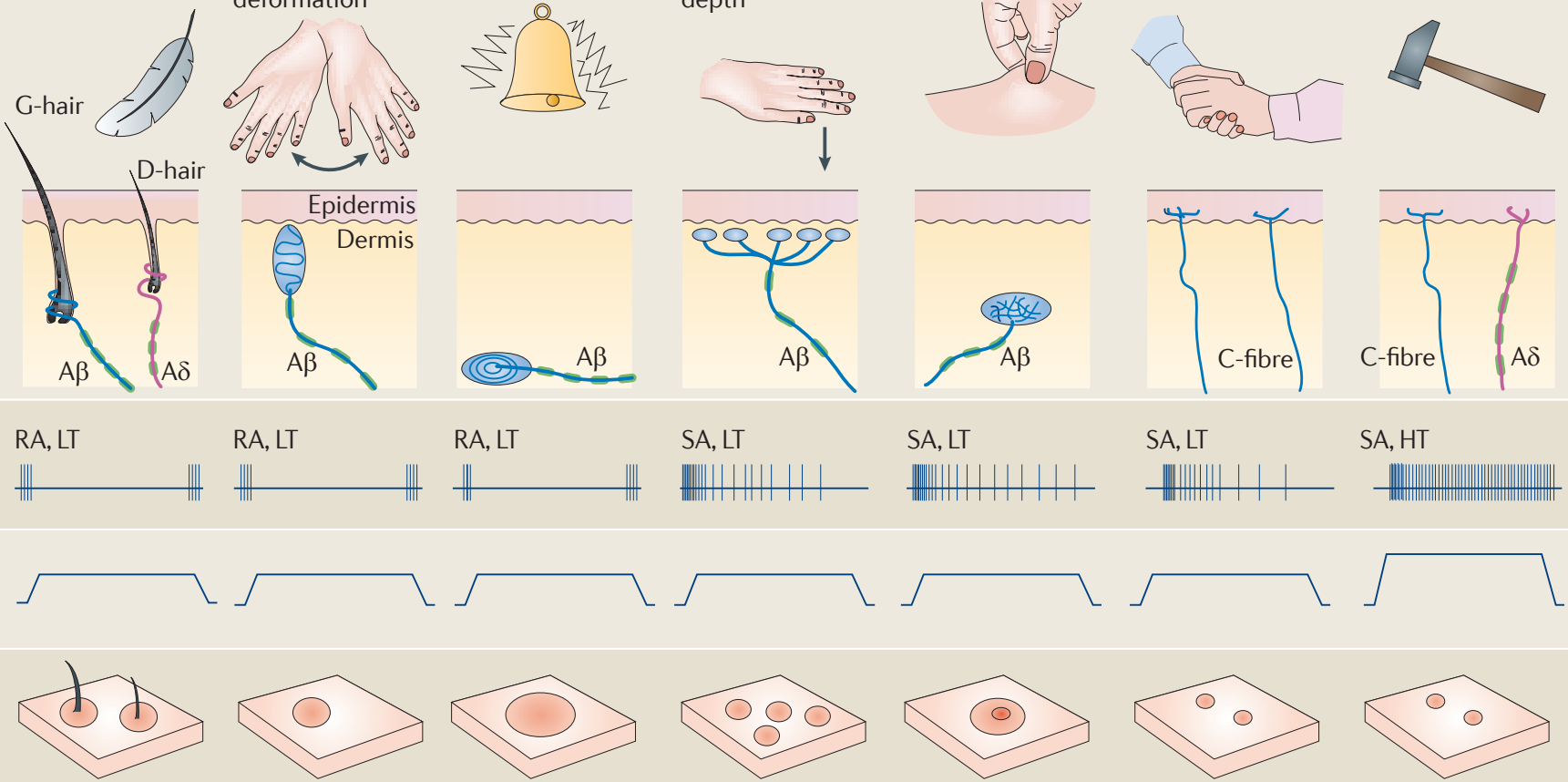

Stimulus
(µm)
9
6
3
0
200 pA
100 ms


Stimulus
(µm)
9
6
3
0
50 pA
20 ms

Receptor subtype	Hair follicles	Meissner corpuscle	Pacinian corpuscle	Merkel cell–neurite complex	Ruffini corpuscle	C-fibre LTM	Mechano-nociceptor Polymodal nociceptor
Skin stimulus	Light brush	Dynamic deformation	Vibration	Indentation depth	Stretch	Touch	Injurious forces
							


Receptor subtype
Hair follicles
Meissner corpuscle
Pacinian corpuscle
Merkel cell–neurite complex
Ruffini corpuscle
C-fibre LTM
Mechano-nociceptor Polymodal nociceptor
Skin stimulus
Light brush
Dynamic deformation
Vibration
Indentation depth
Stretch
Touch
Injurious forces
G-hair
D-hair
Aβ
Aδ
Epidermis
Dermis
Aβ
Aβ
Aβ
Aβ
C-fibre
C-fibre
Aδ
Afferent response
RA, LT
RA, LT
RA, LT
SA, LT
SA, LT
SA, LT
SA, HT
Stimulus

Receptor subtype	Hair follicles	Meissner corpuscle	Pacinian corpuscle	Merkel cell–neurite complex	Ruffini corpuscle	C-fibre LTM	Mechano-nociceptor Polymodal nociceptor
Skin stimulus	Light brush	Dynamic deformation	Vibration	Indentation depth	Stretch	Touch	Injurious forces
Afferent response	RA, LT	RA, LT	RA, LT	SA, LT	SA, LT	SA, LT	SA, HT
Stimulus							
Receptive field							



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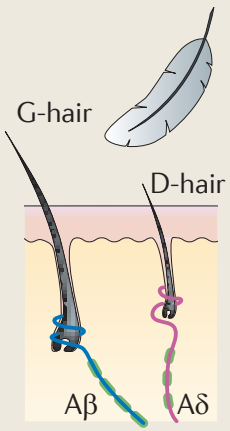
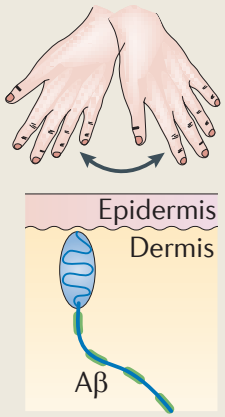
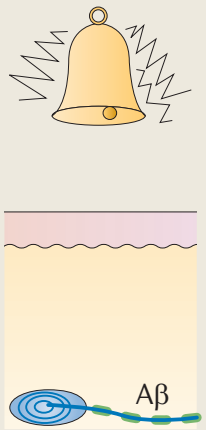
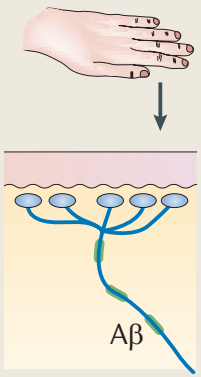
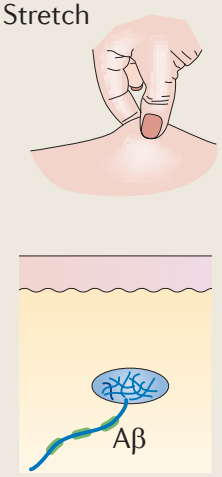
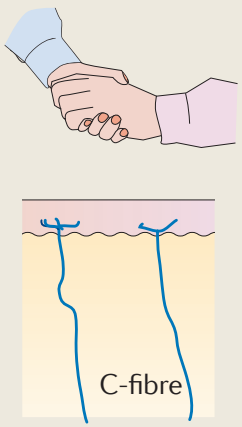
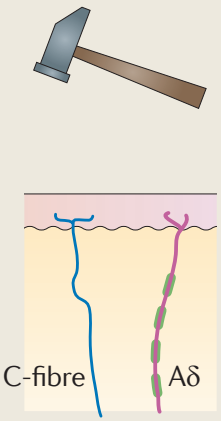
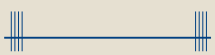
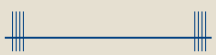
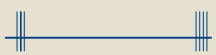
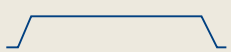
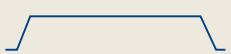
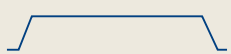
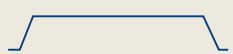
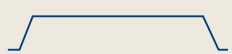
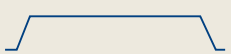
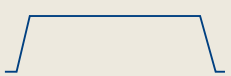
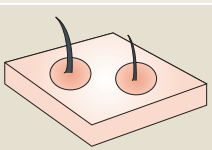
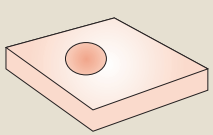
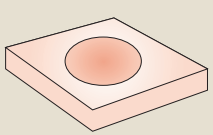
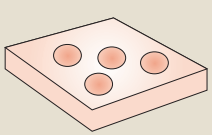
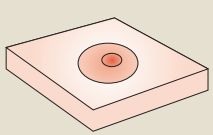
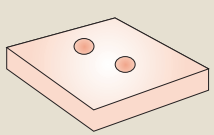
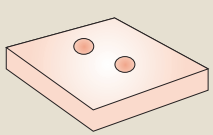
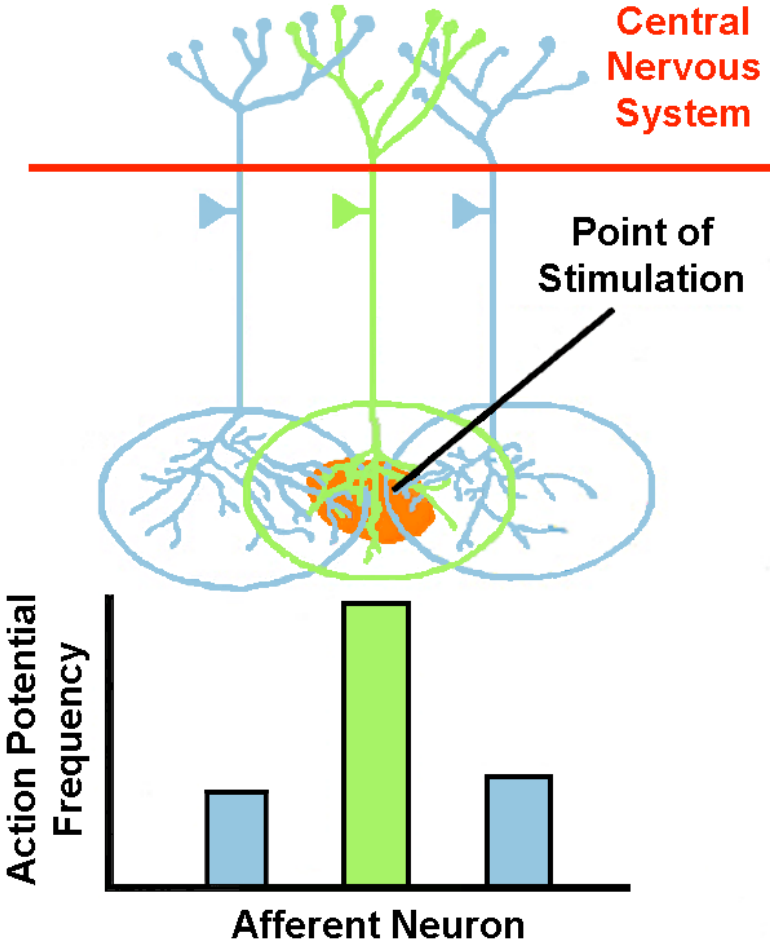
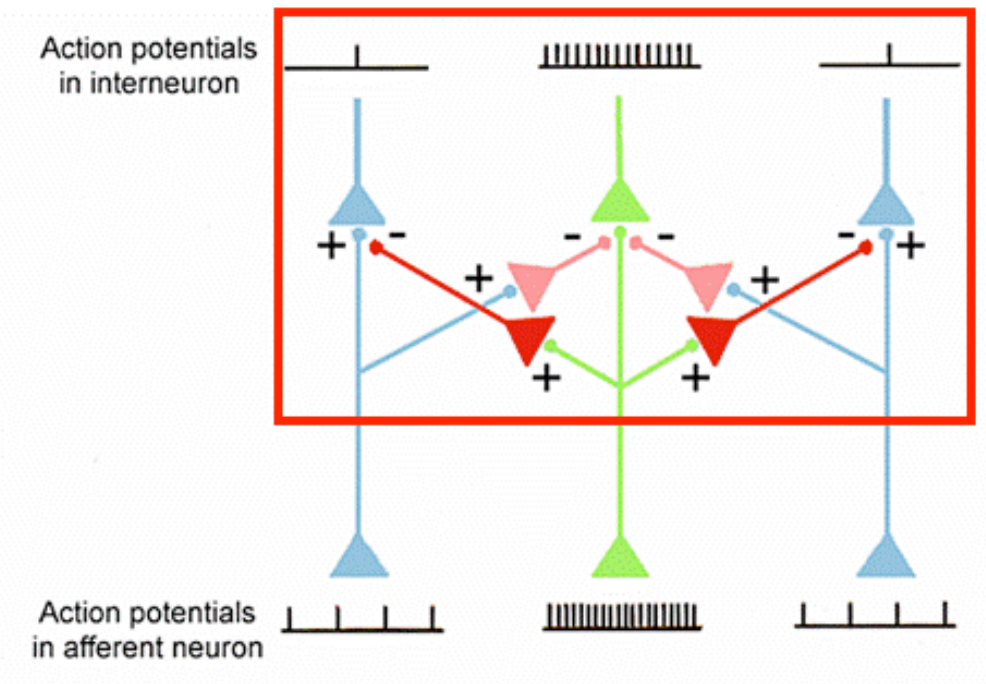
							
Afferent response	RA, LT	RA, LT	RA, LT	SA, LT	SA, LT	SA, LT	SA, HT
							
Stimulus							
							
Receptive field							
Perceptual functions	Skin movement	Skin motion; detecting slipping objects	Vibratory cues transmitted by body contact when grasping an object	Fine tactile discrimination; form and texture perception	Skin stretch; direction of object motion, hand shape and finger position	Pleasant contact; social interaction	Skin injury; pain

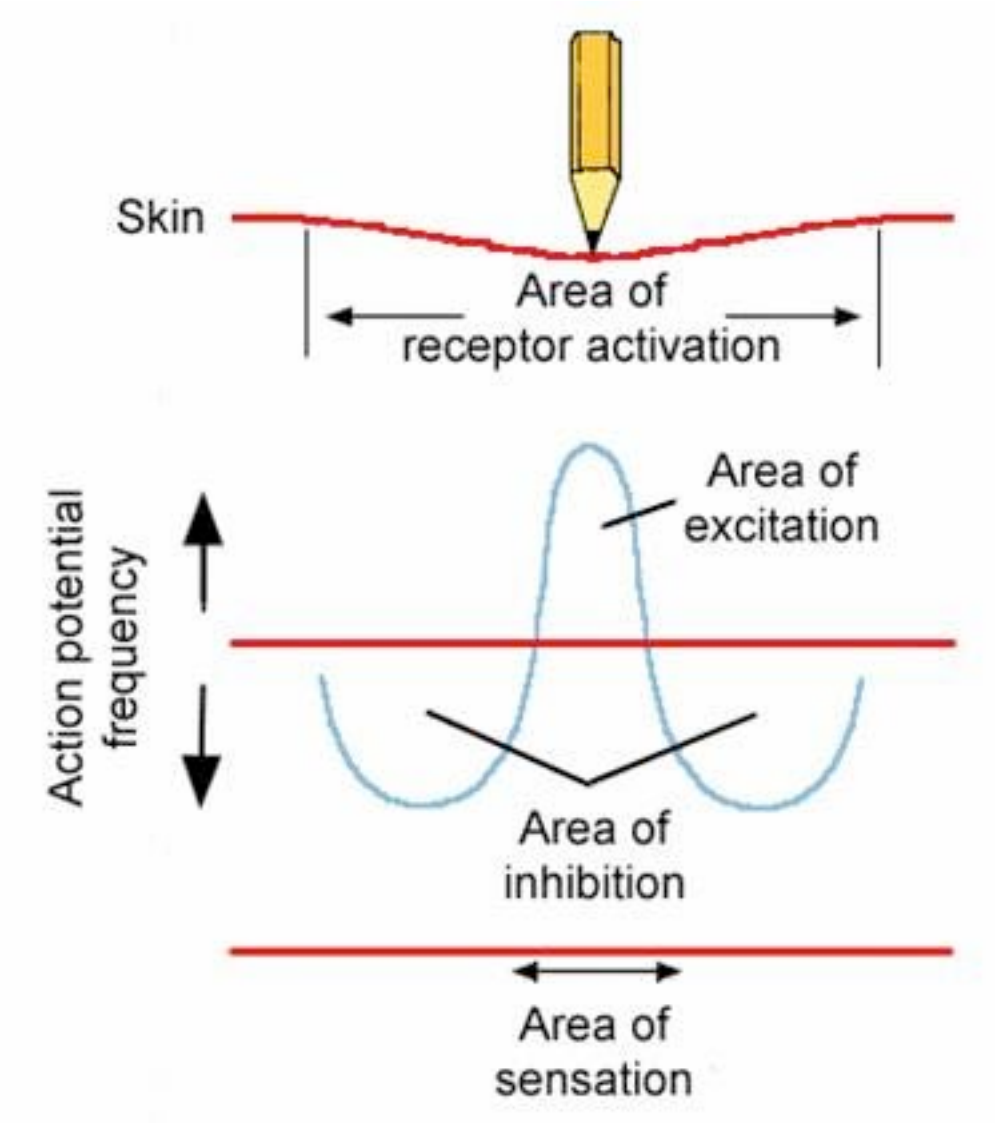
Inhibitory surround/ lateral inhibition

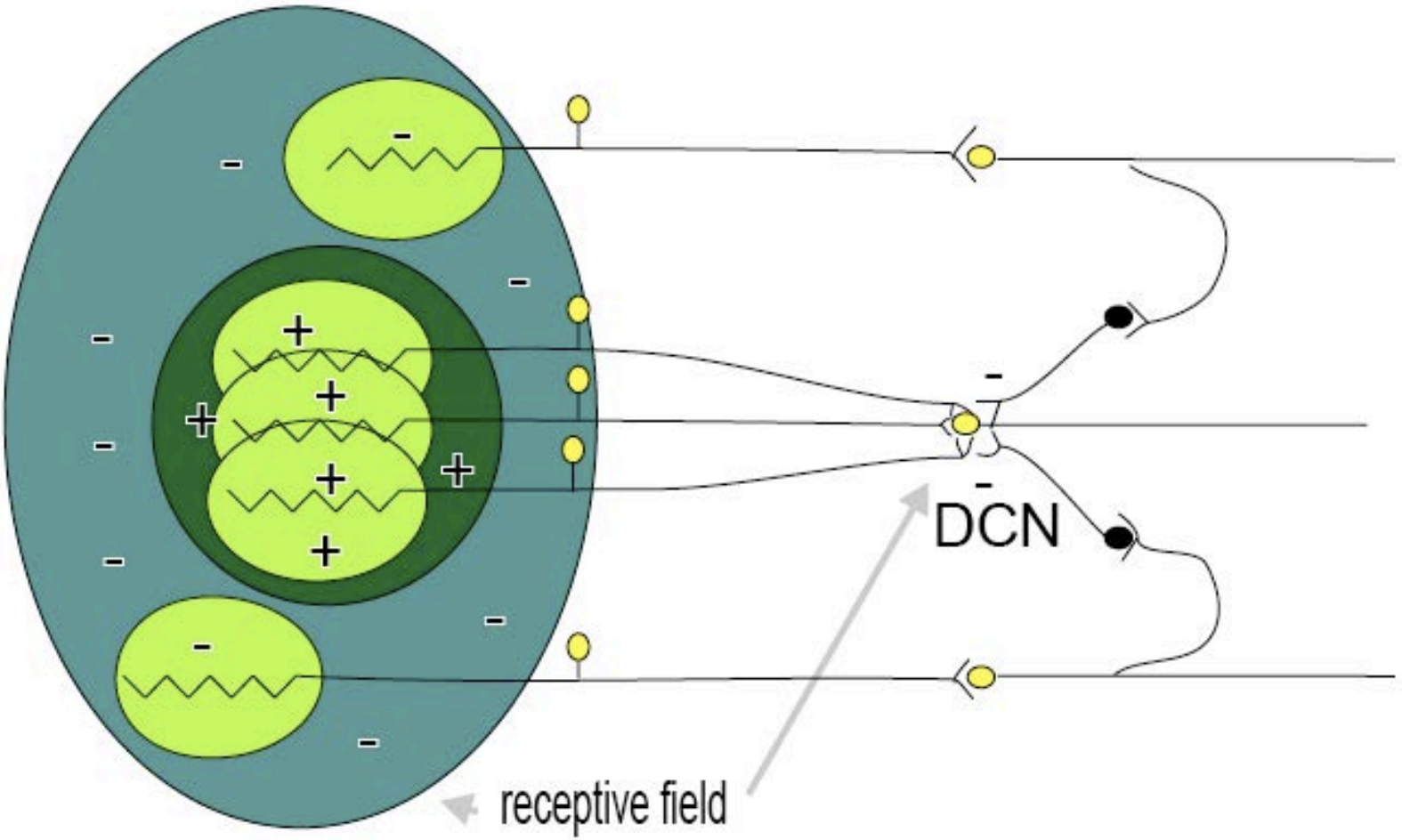
--like center-surround for RGCs
--lateral inhibition in relay nuclei (DCN)
--want to sense change, contrast
--improve spatial acuity

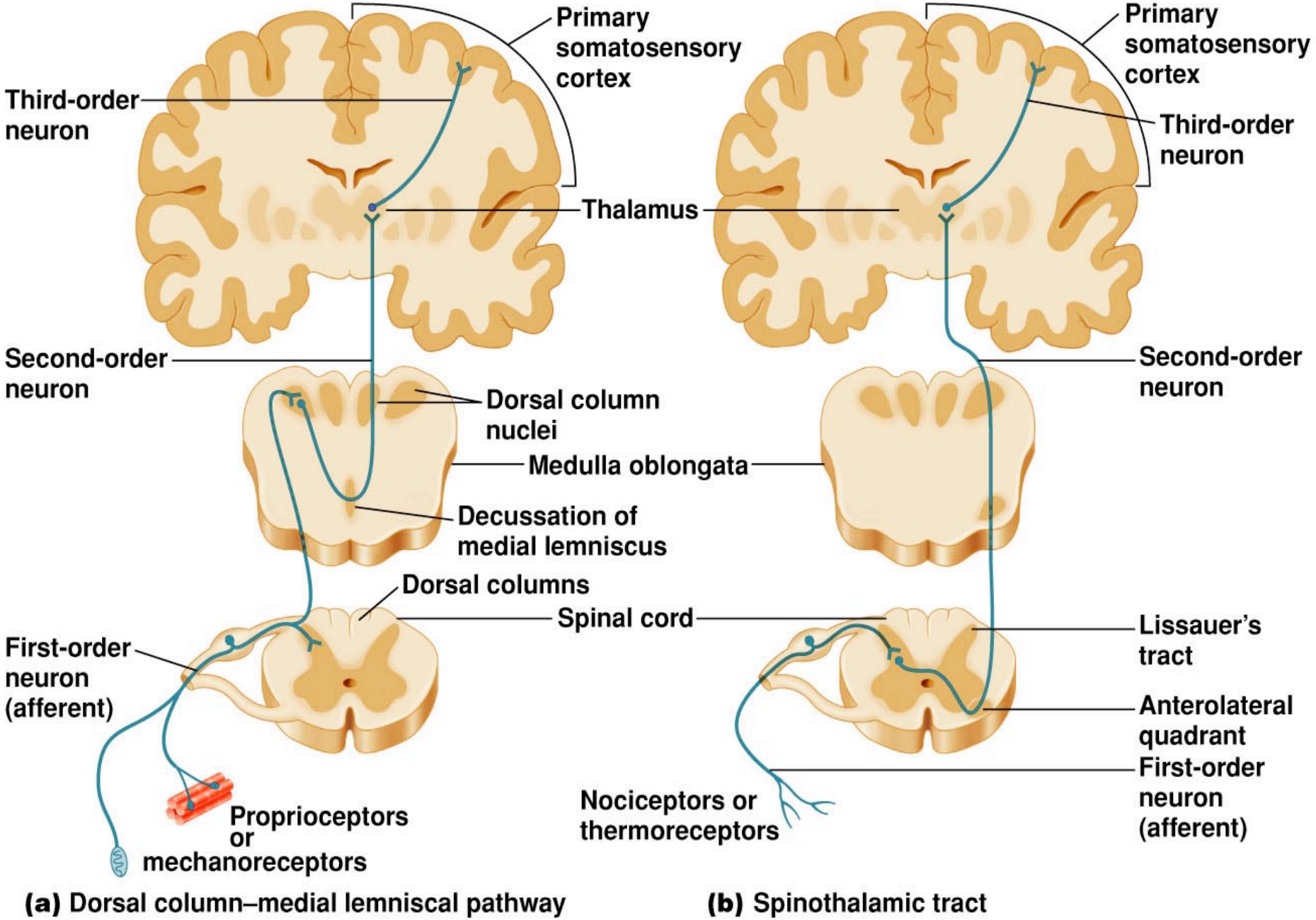
--feedforward inhibition: spatial focusing, WTA
--feedback from higher centers: context, attention


Central Nervous System
Point of Stimulation
Action Potential Frequency
Afferent Neuron

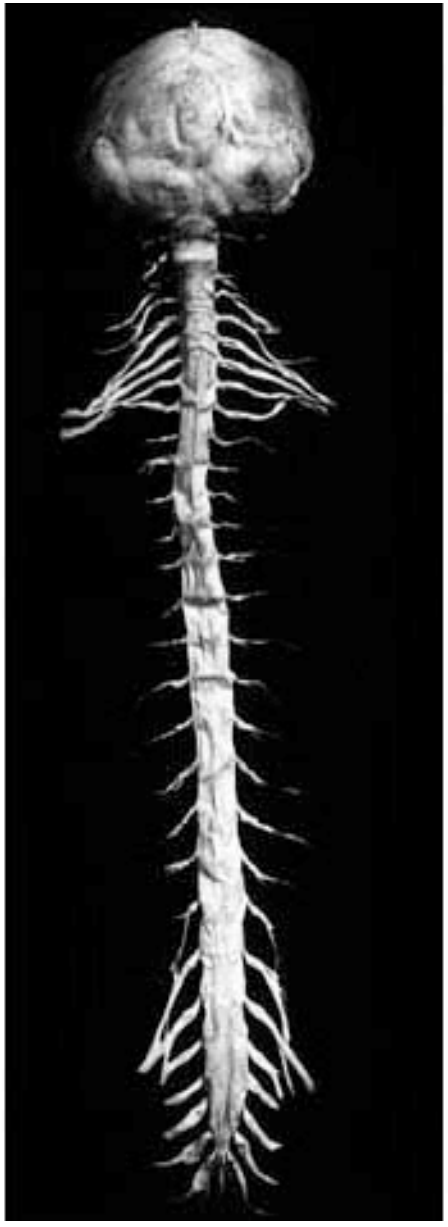

Action potentials in interneuron
Action potentials in afferent neuron

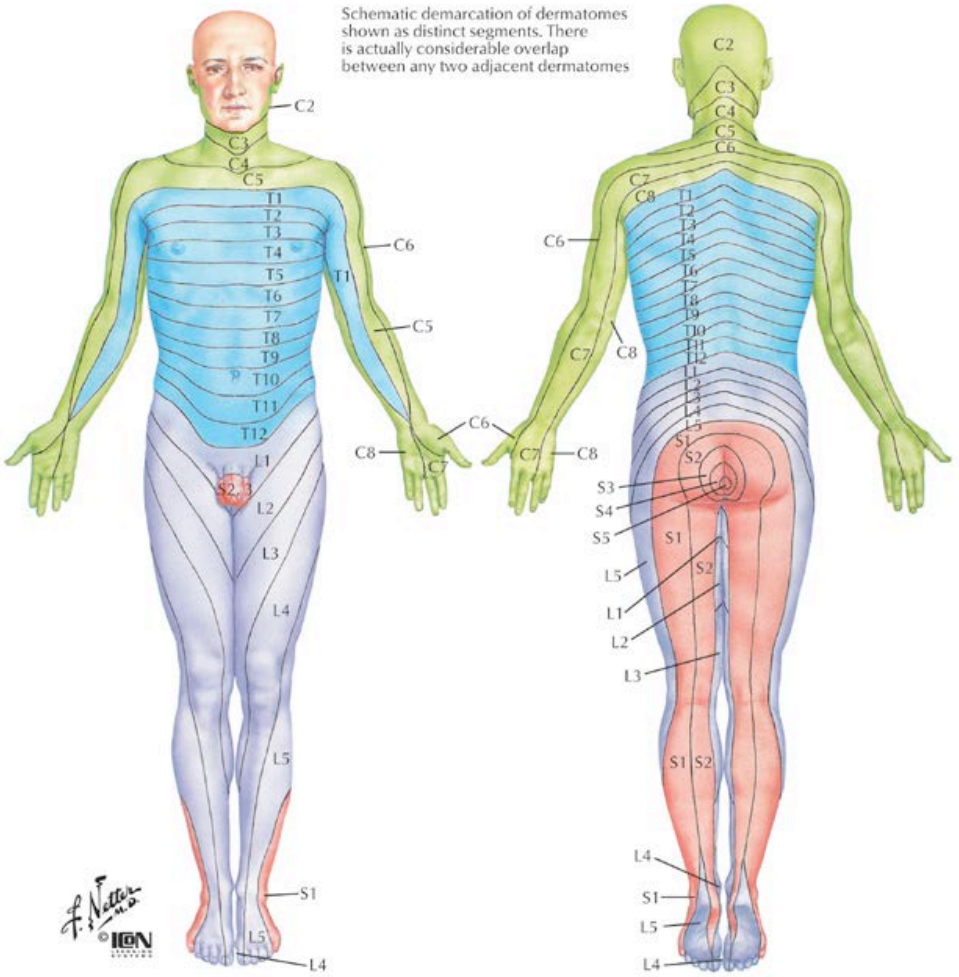

Skin
Area of
receptor activation
Action potential
frequency
Area of
excitation
Area of
inhibition
Area of
sensation


DCN
receptive field



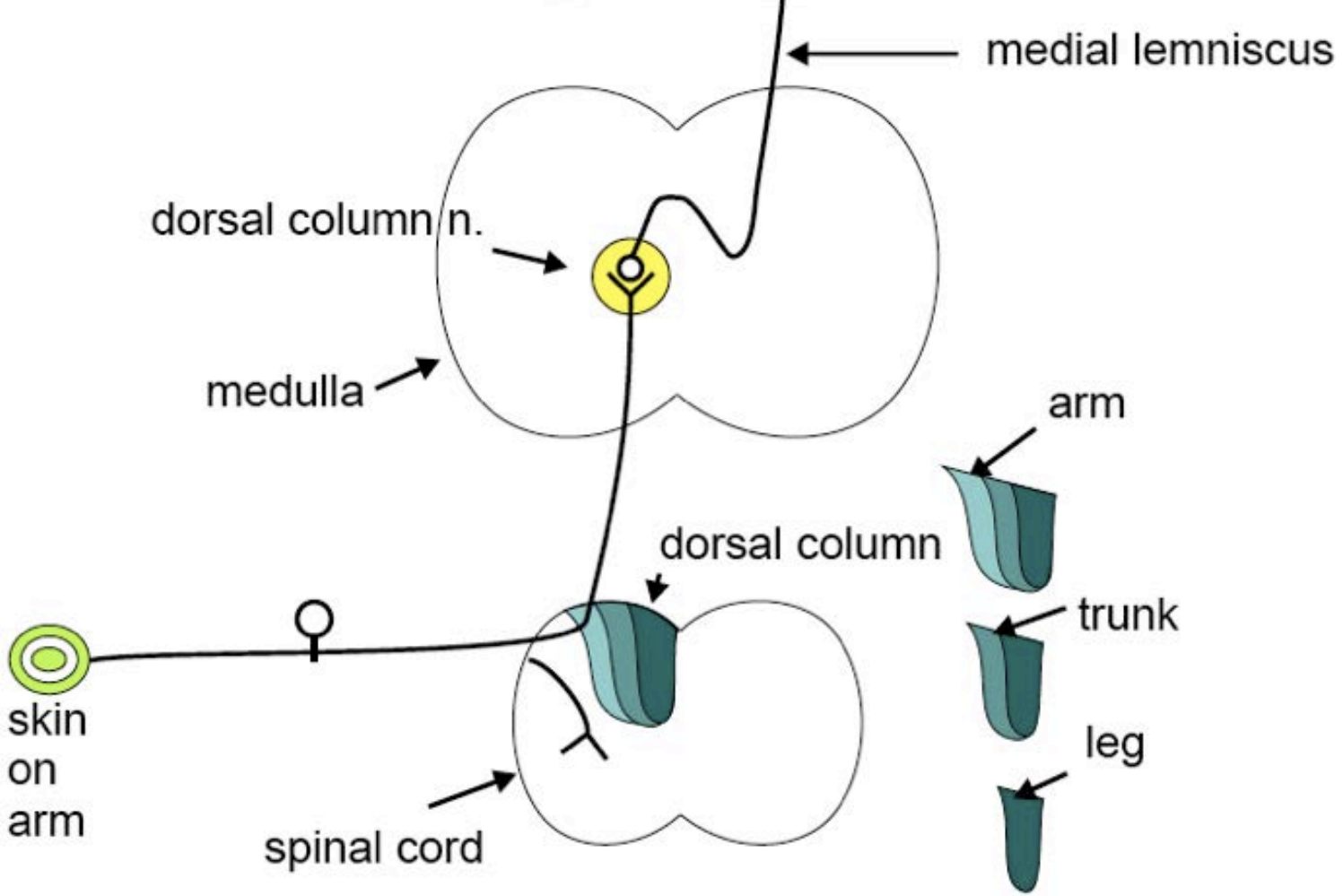
The dorsal-column medial-lemniscus system for touch

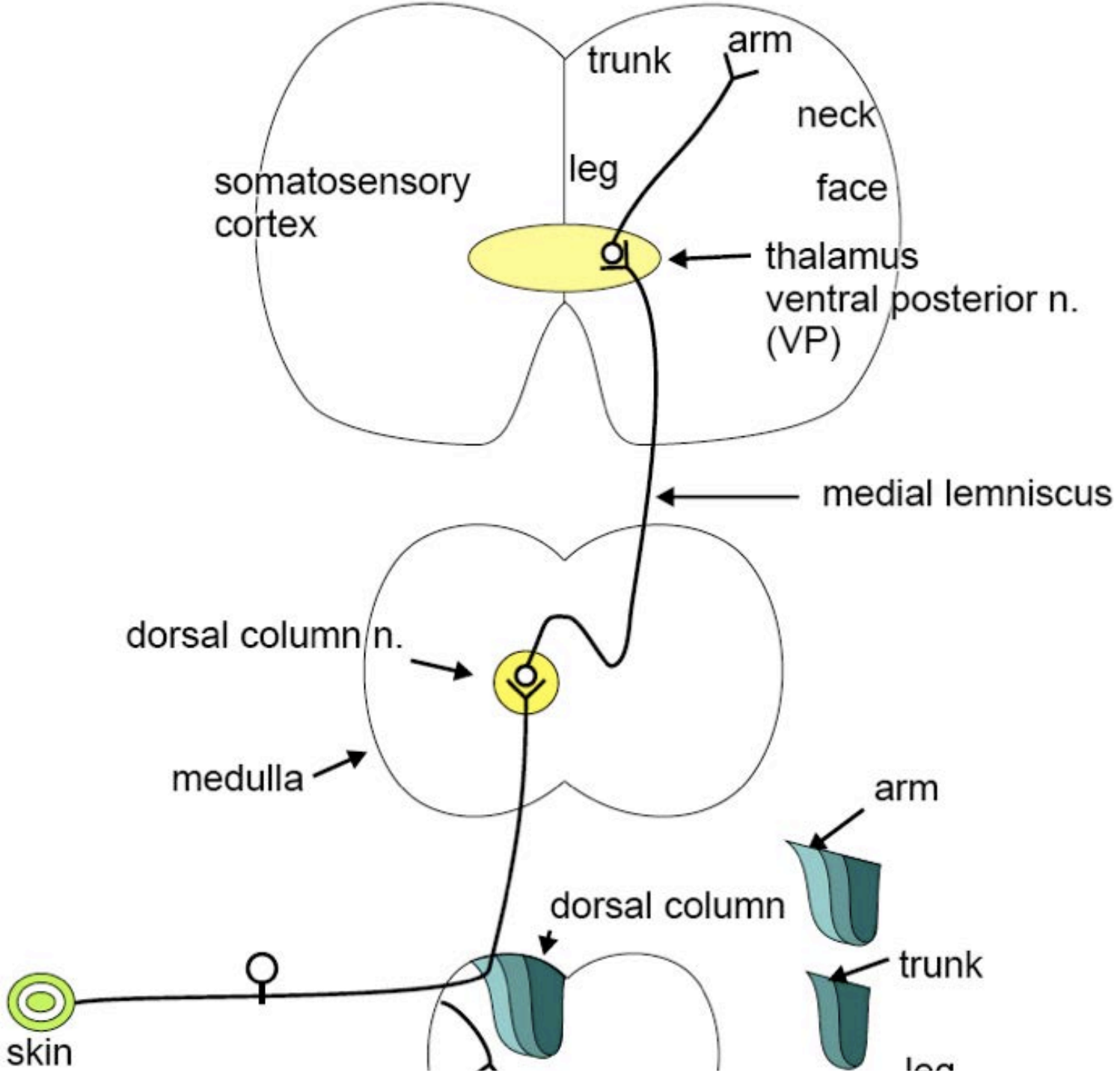




Levels of principal dermatomes

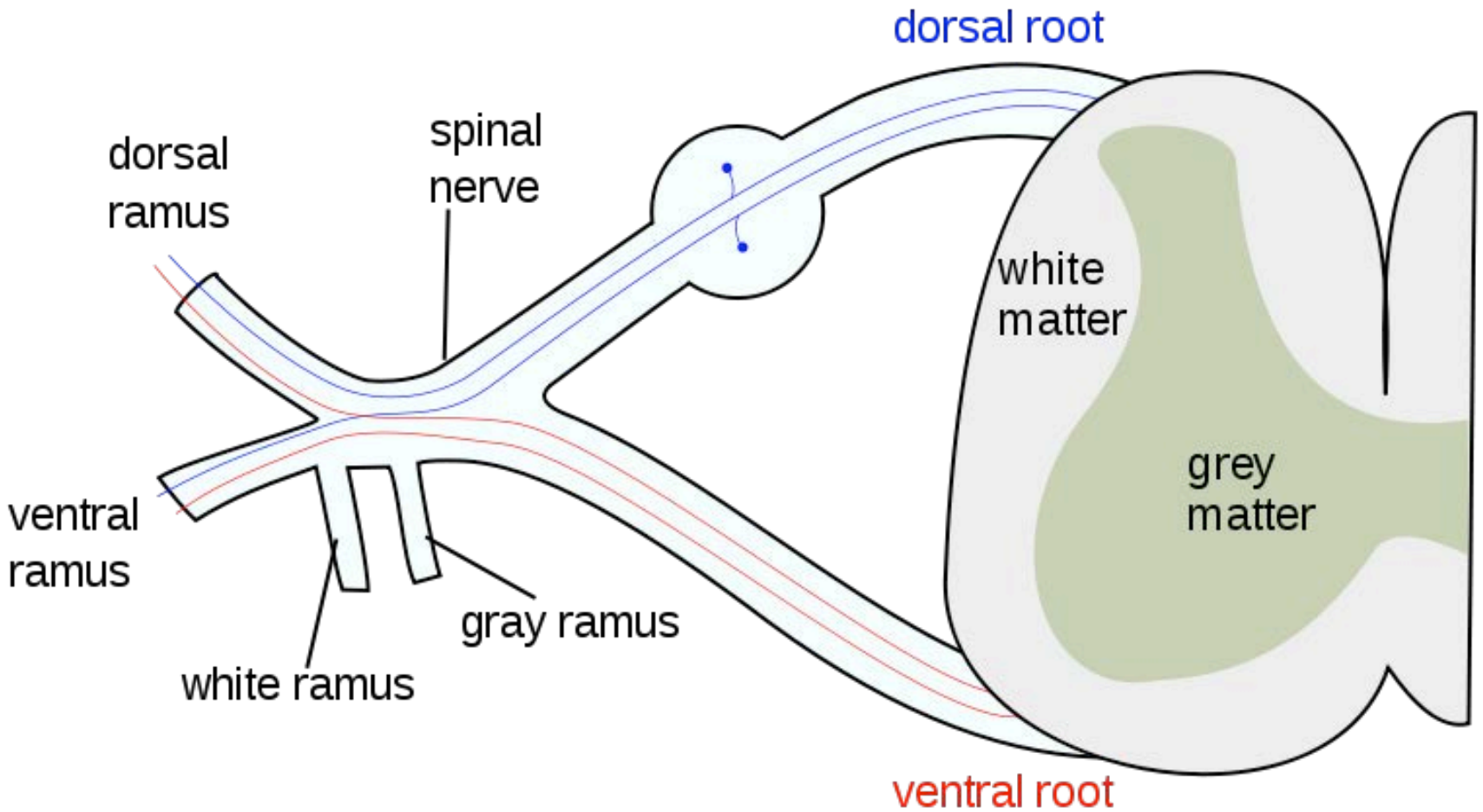
C5	Clavicles
C5, 6, 7	Lateral parts of upper limbs
C8, T1	Medial sides of upper limbs
C6	Thumb
C6, 7, 8	Hand
C8	Ring and little fingers
T4	Level of nipples
T10	Level of umbilicus
T12	Inguinal or groin regions
L1, 2, 3, 4	Anterior and inner surfaces of lower limbs
L4, 5, S1	Foot
L4	Medial side of great toe
S1, 2, L5	Posterior and outer surfaces of lower limbs
S1	Lateral margin of foot and little toe
S2, 3, 4	Perineum

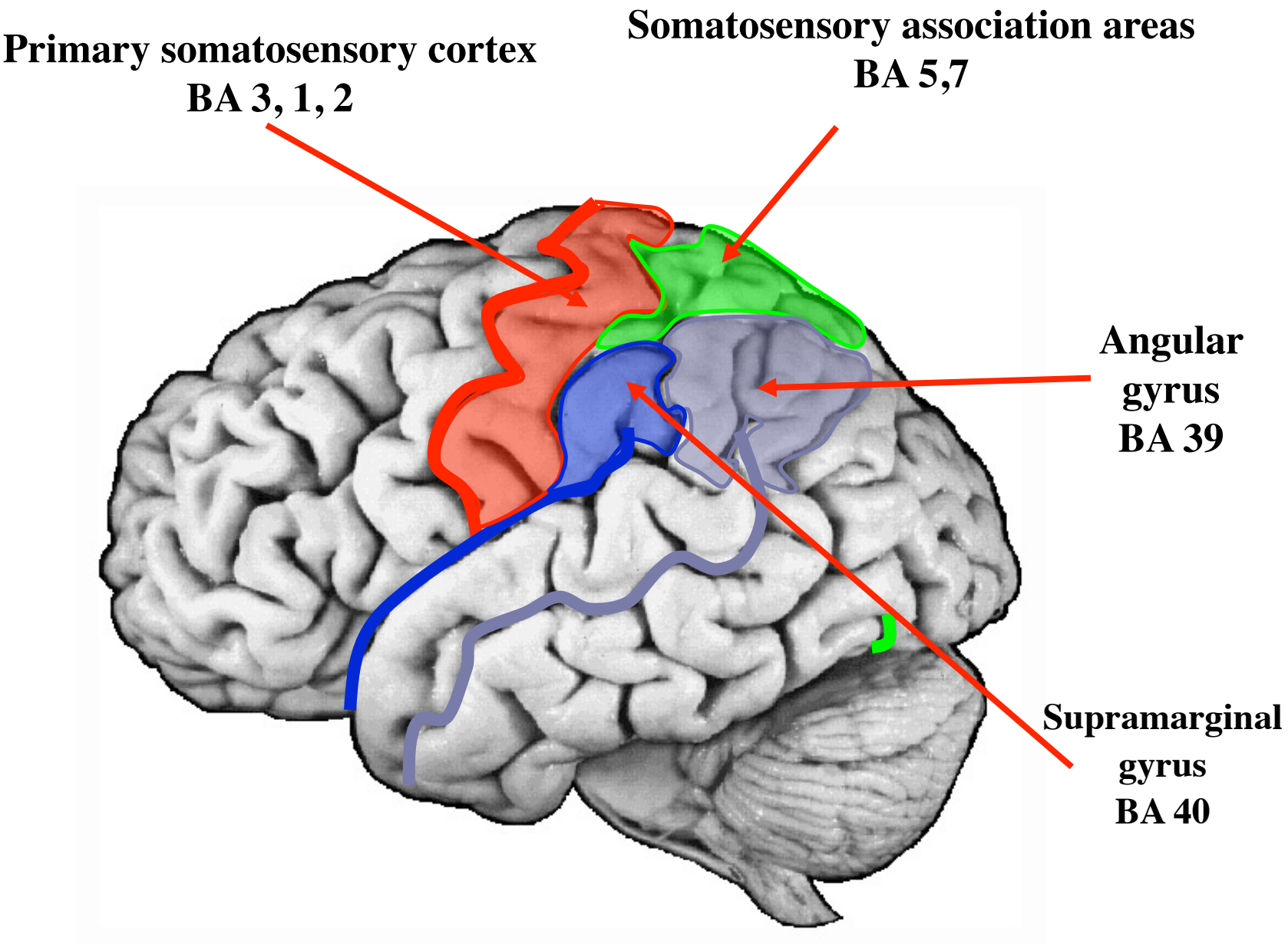

medial lemniscus
dorsal column n.
medulla
arm
dorsal column
trunk
leg
skin
on
arm
spinal cord

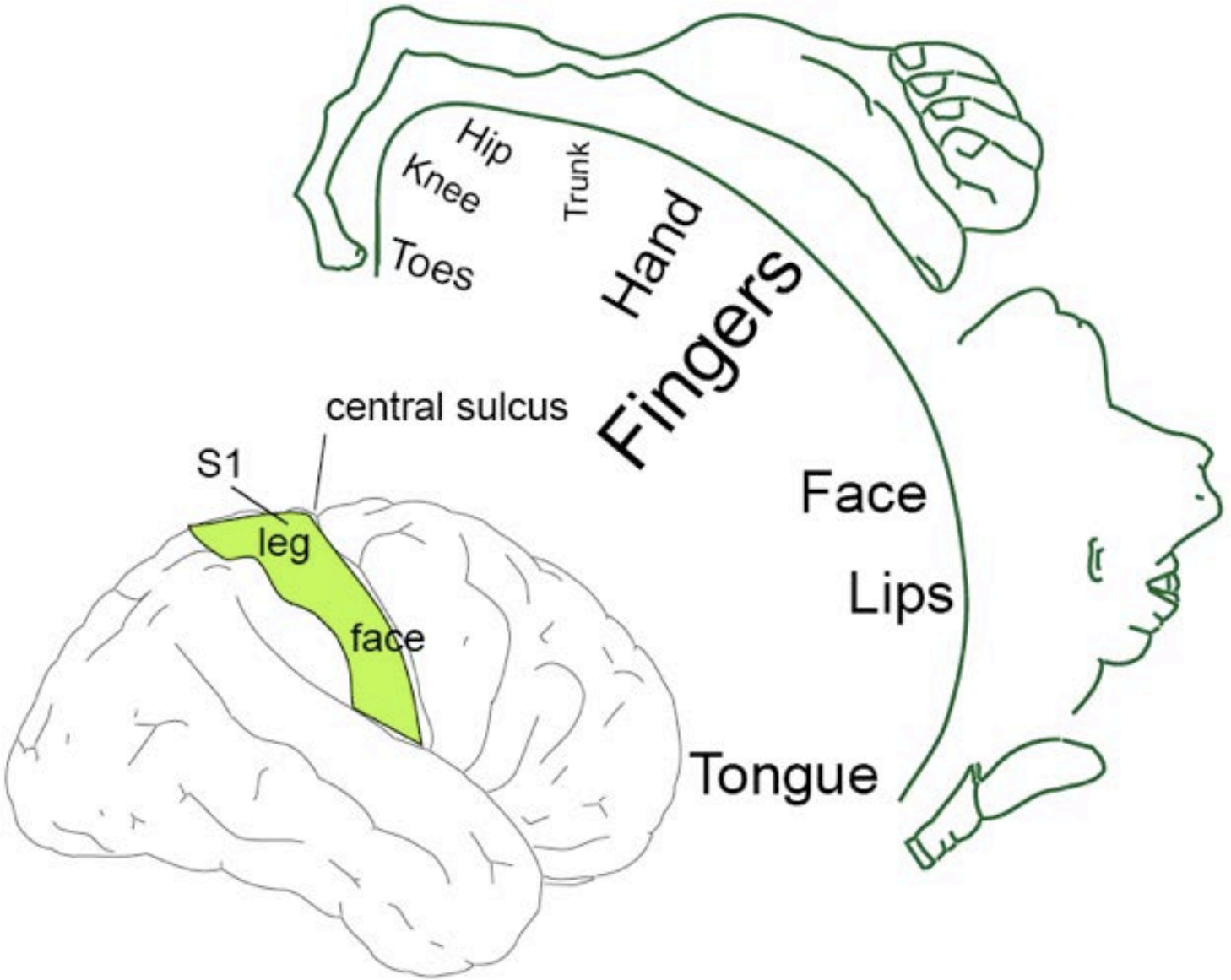

trunk
arm
neck
leg
face
somatosensory cortex
thalamus
ventral posterior n. (VP)
medial lemniscus
dorsal column n.
medulla
arm
dorsal column
trunk
skin

Face/ Head:

Trigeminal nerve


dorsal root
dorsal ramus
spinal nerve
white matter
grey matter
ventral ramus
gray ramus
white ramus
ventral root

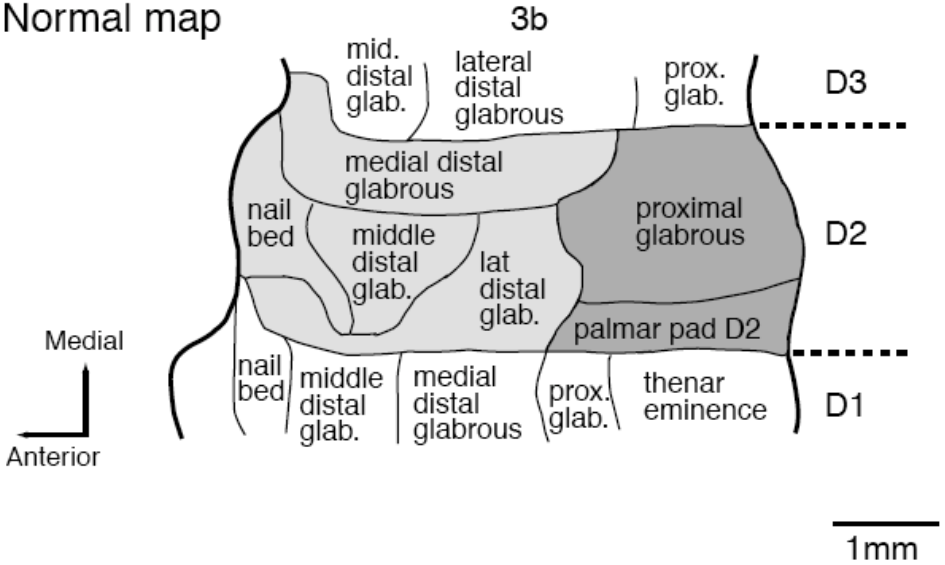

Primary somatosensory cortex
BA 3, 1, 2
Somatosensory association areas
BA 5,7
Angular
gyrus
BA 39
Supramarginal
gyrus
BA 40


Hip
Knee
Toes
Trunk
Hand
Fingers
central sulcus
S1
leg
face
Face
Lips
Tongue

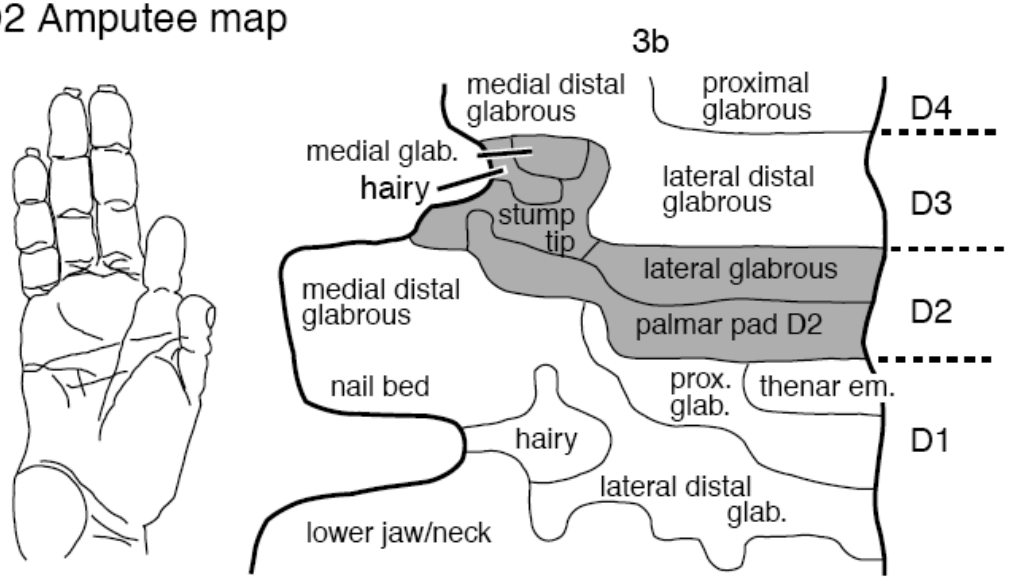
There is substantial plasticity!

40

D2 Normal map



D2 Amputee map

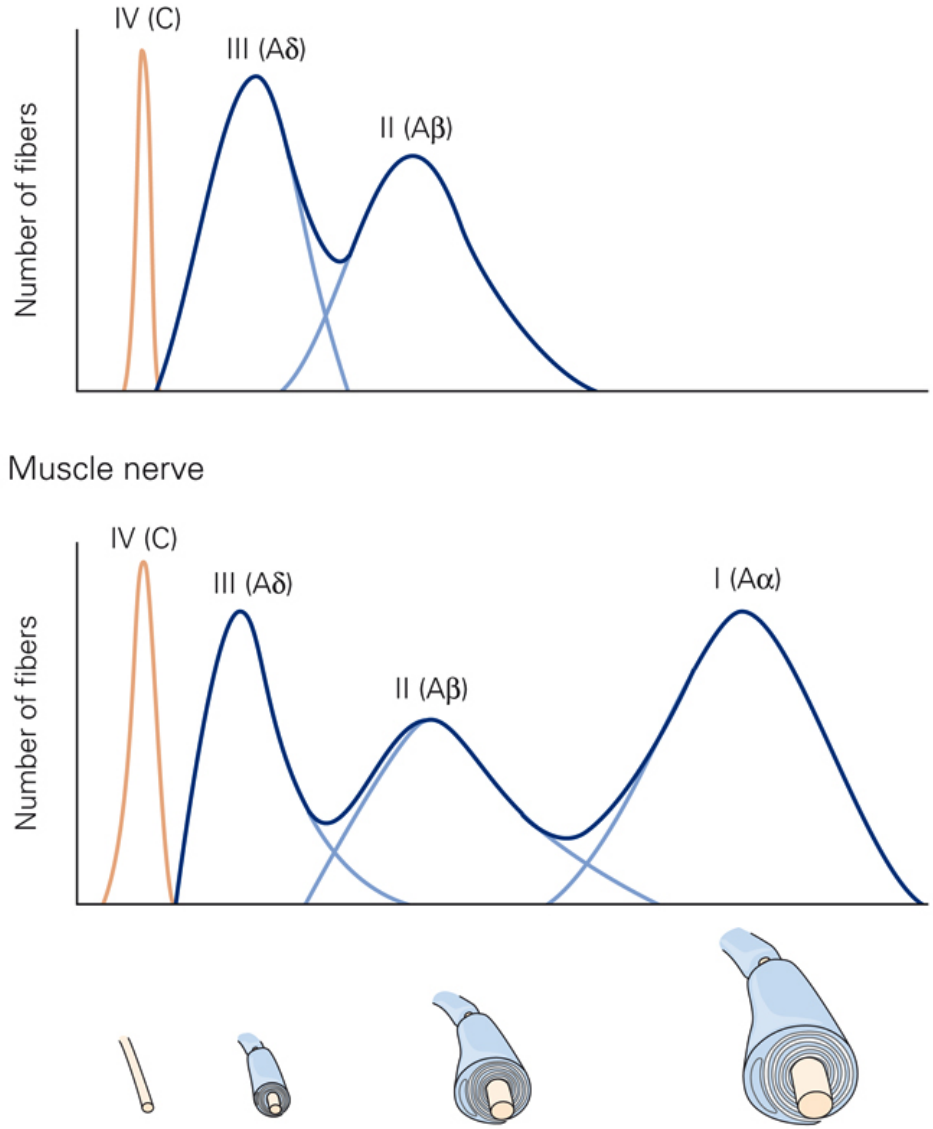


A-delta and C fiber afferents:

Pain, temperature

Hypoxia, hypoglycemia, hypo-osmolarity, lactate/ pH

Social touch



Axon diameter (μm)	1	5	12	20
Conduction velocity (m/s)	1	30	72	120

Figure 22–2 Peripheral nerves innervating skeleta
cle and the skin contain several types of sensory r
fibers. The graphs illustrate the distribution of four gr
sensory nerve fibers innervating skeletal muscle and
Each group has a characteristic axon diameter and co
velocity. **Light blue lines** are the sum of fibers in eac
in the zones of overlap. The conduction velocity of my
peripheral nerve fibers is approximately six times the
diameter. (Adapted, with permission, from Boyd and
1968.)

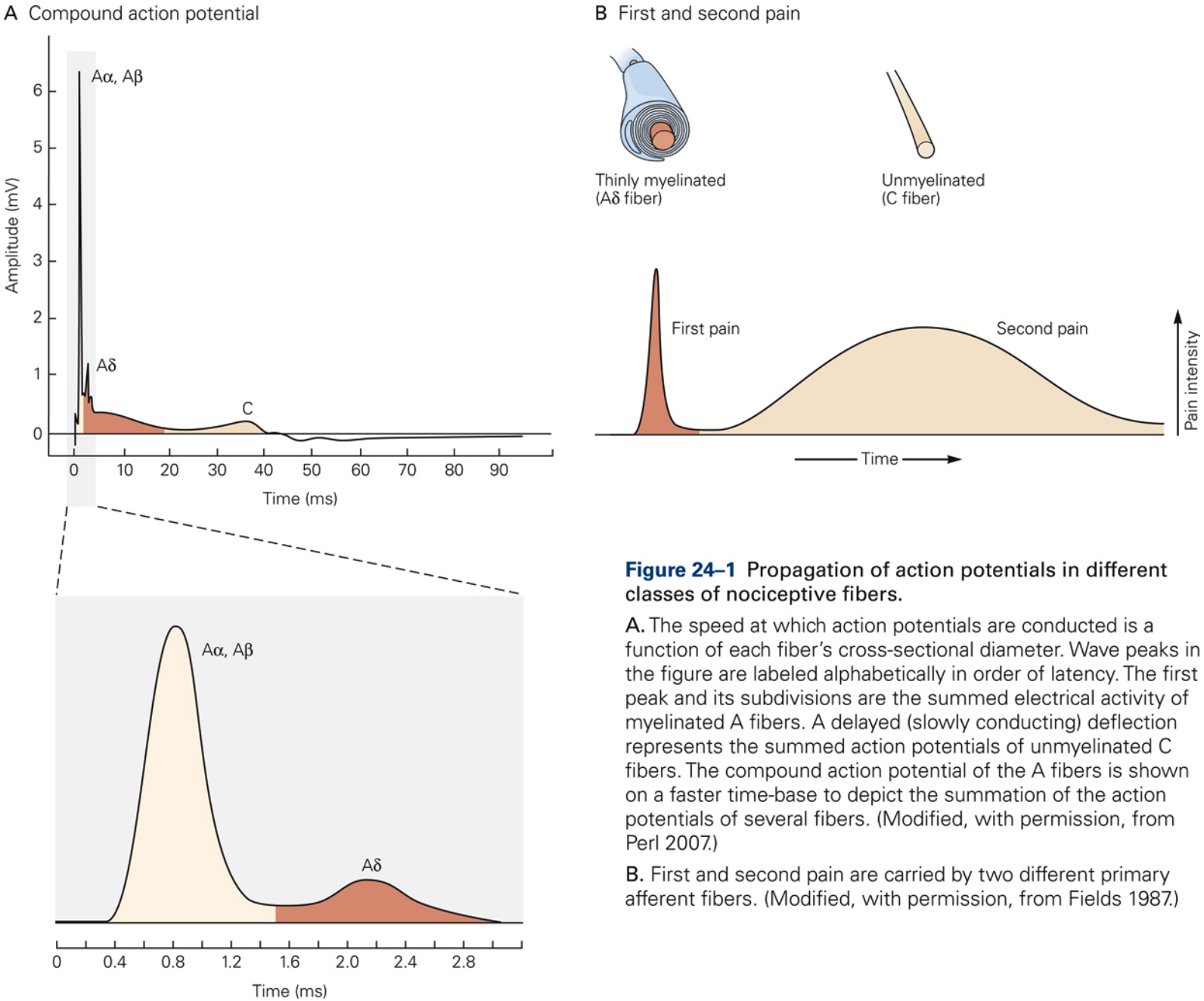
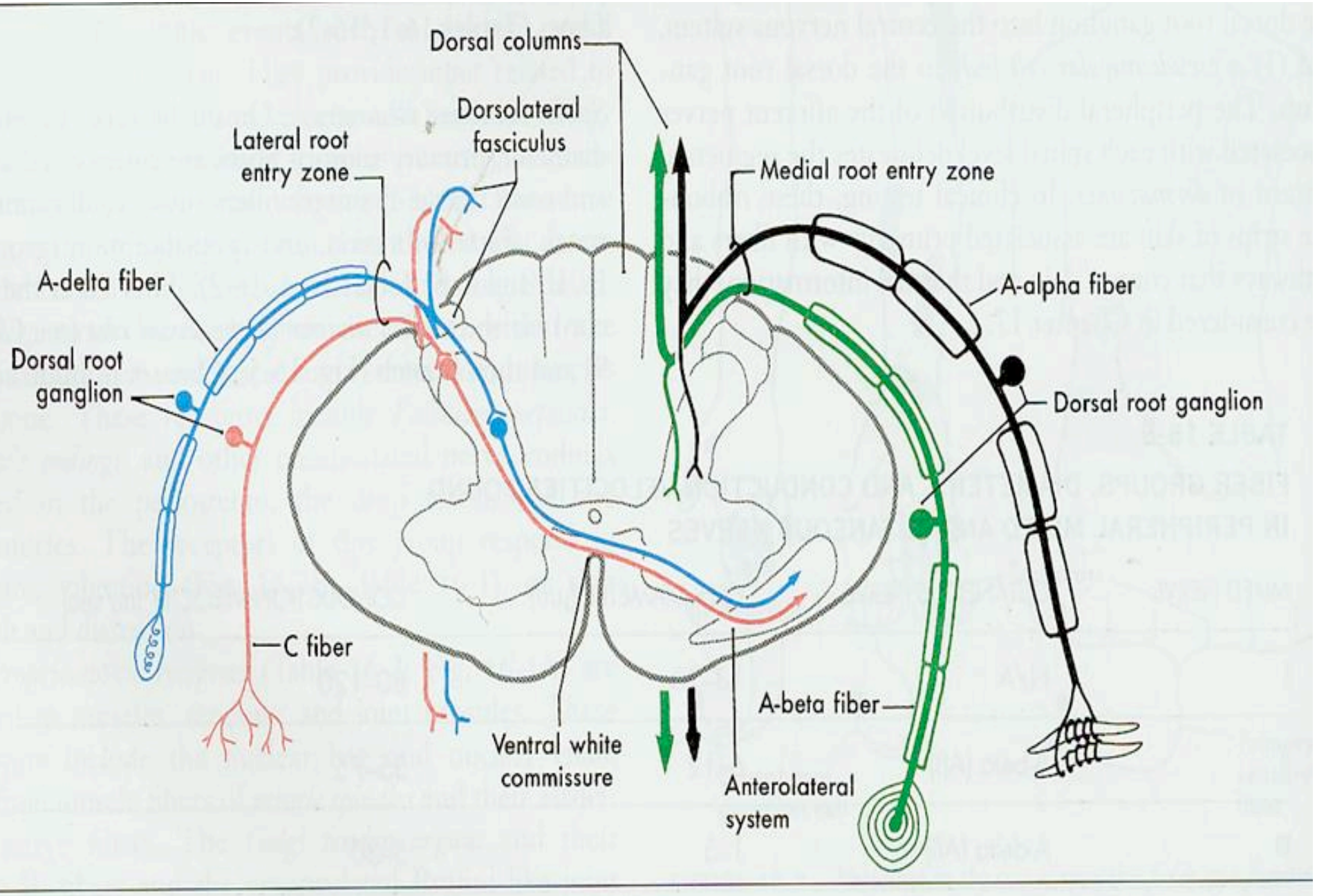
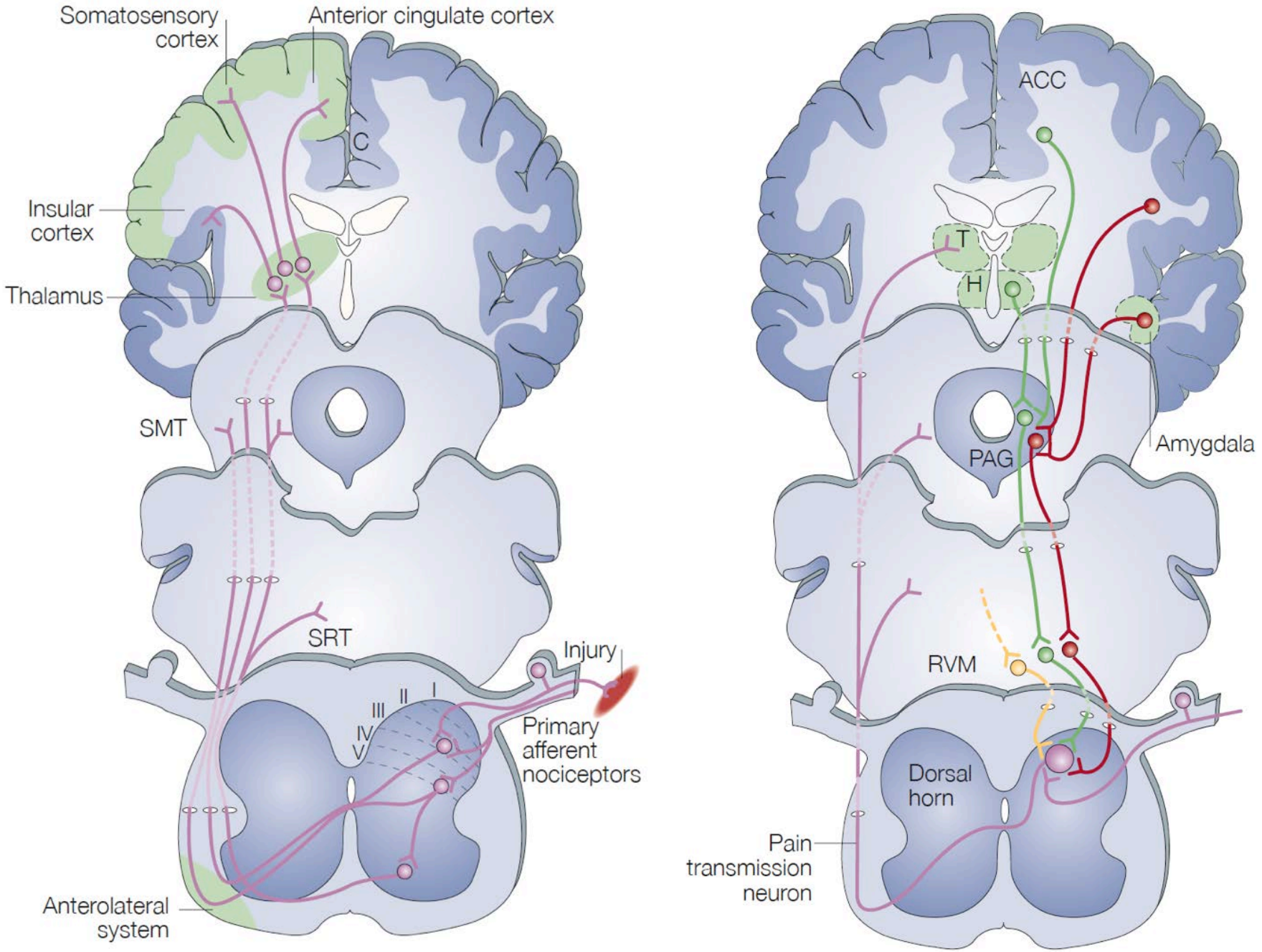


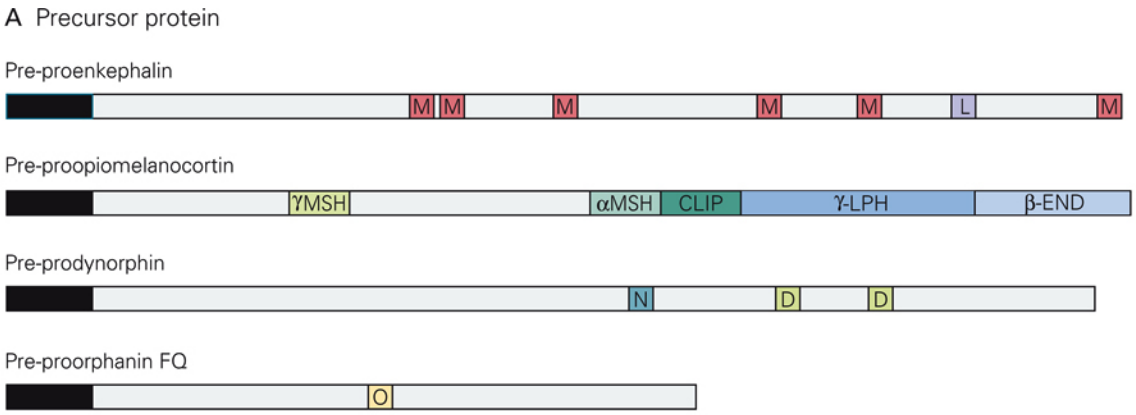
Figure 24–1 Propagation of action potentials in different classes of nociceptive fibers.

A. The speed at which action potentials are conducted is a function of each fiber's cross-sectional diameter. Wave peaks in the figure are labeled alphabetically in order of latency. The first peak and its subdivisions are the summed electrical activity of myelinated A fibers. A delayed (slowly conducting) deflection represents the summed action potentials of unmyelinated C fibers. The compound action potential of the A fibers is shown on a faster time-base to depict the summation of the action potentials of several fibers. (Modified, with permission, from Perl 2007.)

B. First and second pain are carried by two different primary afferent fibers. (Modified, with permission, from Fields 1987.)


Dorsal columns
Dorsolateral fasciculus
Lateral root entry zone
Medial root entry zone
A-delta fiber
A-alpha fiber
Dorsal root ganglion
Dorsal root ganglion
C fiber
A-beta fiber
Ventral white commissure
Anterolateral system


Somatosensory cortex
Anterior cingulate cortex
C
Insular cortex
Thalamus
SMT
SRT
Injury
Primary afferent nociceptors
I
II
III
IV
V
Anterolateral system
ACC
T
H
PAG
Amygdala
RVM
Dorsal horn
Pain transmission neuron



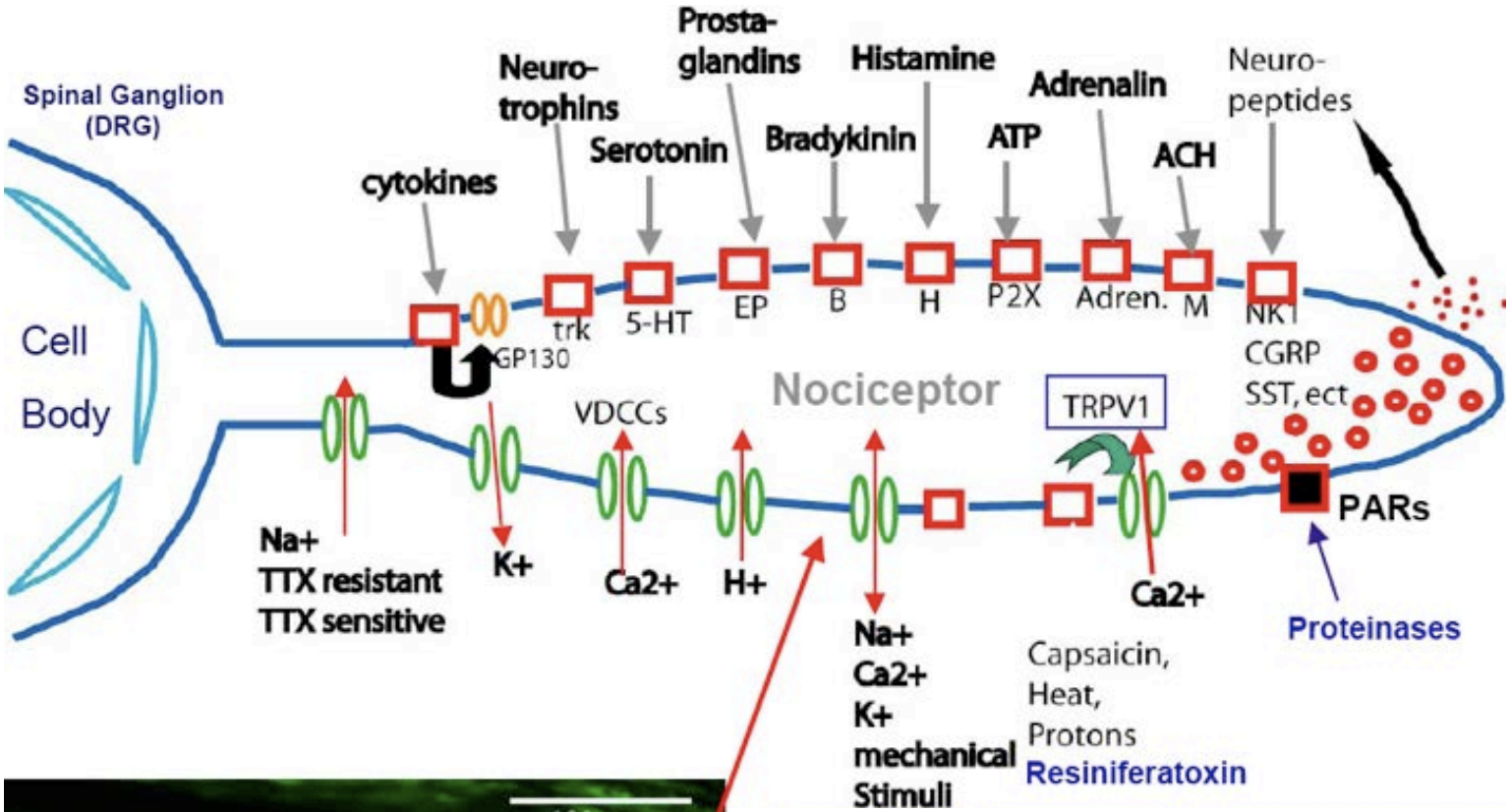
B Proteolytically processed opioid peptides

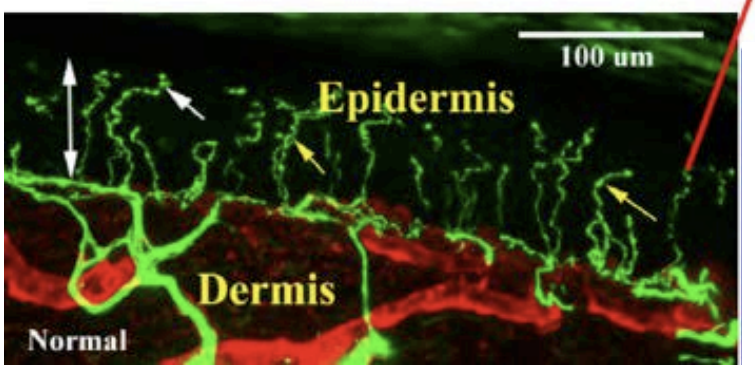
		Amino acid sequence
M	Methionine-enkephalin	**Tyr Gly Gly Phe** Met OH
L	Leucine-enkephalin	**Tyr Gly Gly Phe** Leu OH
β-END	β-Endorphin	**Tyr Gly Gly Phe** Met Thr Ser Glu Lys Ser Gln Thr Pro Leu Val Thr Leu Phe Lys Asn Ala Ile Val Lys Asn Ala His Lys Gly Gln OH
D	Dynorphin	**Tyr Gly Gly Phe** Leu Arg Arg Ile Arg Pro Lys Leu Lys Trp Asp Asn Gln OH
N	α-Neoendorphin	**Tyr Gly Gly Phe** Leu Arg Lys Tyr Pro Lys
O	Orphanin FQ	**Tyr Gly Gly Phe** Thr Gly Ala Arg Lys Ser Ala Arg Lys Leu Ala Asn Gln

Figure 24–16 Four families of endogenous opioid peptides arise from large precursor polyproteins.

A. Each of the precursor molecules is cleaved by proteolytic enzymes to generate shorter, biologically active peptides, some of which are shown in this diagram. The proenkephalin precursor protein contains multiple copies of methionine-enkephalin (M), leucine-enkephalin (L), and several extended enkephalins. Proopiomelanocortin (POMC) contains β-endorphin, melanocyte-stimulating hormone (MSH), adrenocorticotropic hormone (ACTH), and corticotropin-like intermediate-lobe peptide (CLIP). The prodynorphin precursor can produce dynorphin (D) and α-neoendorphin (N). The pro-orphanin precursor contains the orphanin FQ peptide (O). The black domains indicate a signal peptide.

B. Amino acid sequences of proteolytically processed bioactive peptides. The amino acid residues shown in bold type mediate interaction with opioid receptors. (Adapted, with permission, from Fields 1987.)


Spinal Ganglion
(DRG)
Cell
Body
cytokines
Neuro-
trophins
Serotonin
Prosta-
glandins
Bradykinin
Histamine
ATP
Adrenalin
ACH
Neuro-
peptides
GP130
trk
5-HT
EP
B
H
P2X
Adren.
M
NK1
CGRP
SST, ect
Nociceptor
VDCCs
TRPV1
PARs
Na+
TTX resistant
TTX sensitive
K+
Ca2+
H+
Ca2+
Proteinases
Na+
Ca2+
K+
mechanical
Stimuli
Capsaicin,
Heat,
Protons
Resiniferatoxin


100 um
Epidermis
Dermis
Normal