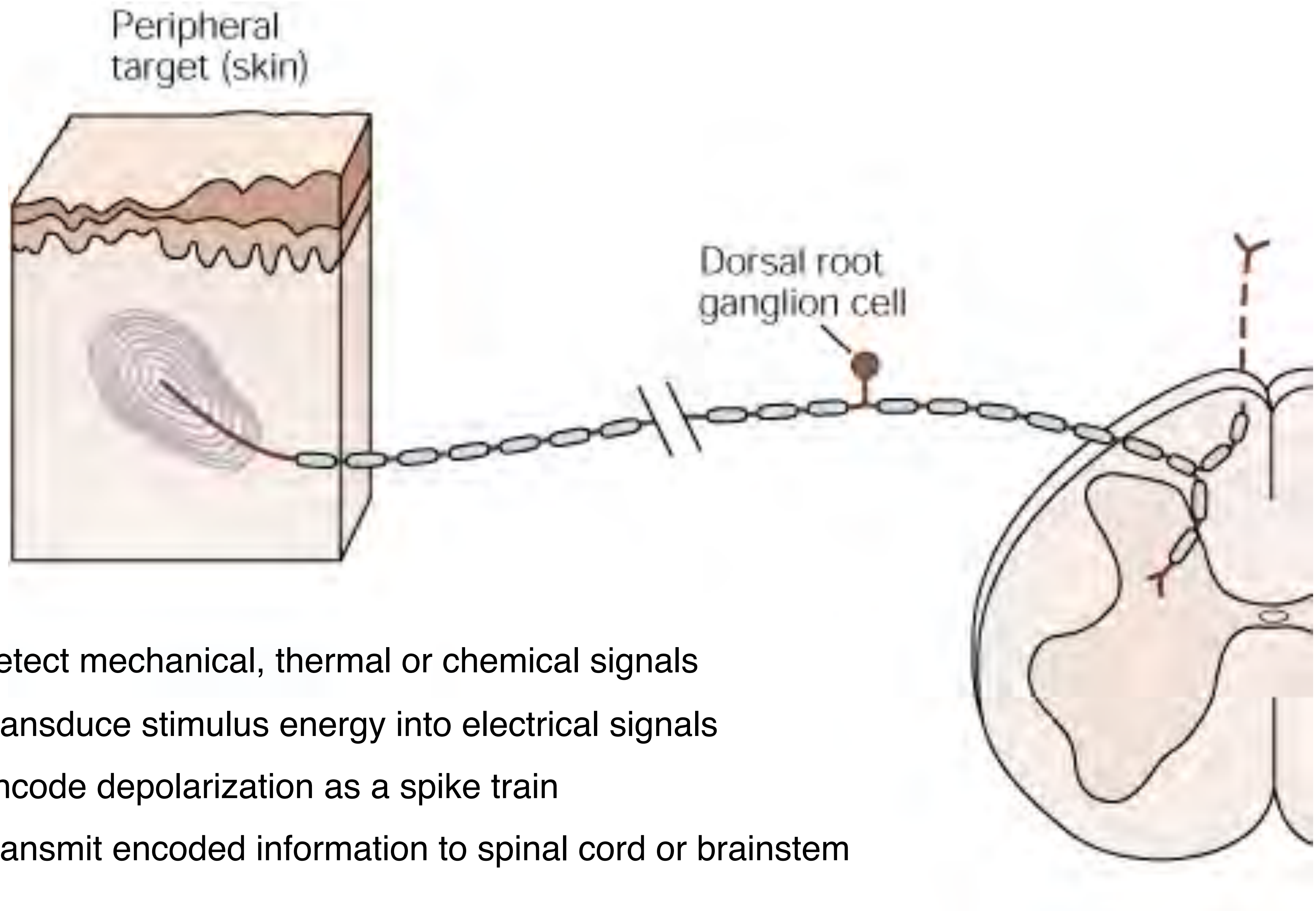
Somatosensory modalities

- The somatosensory system codes five major sensory modalities:
  1. Discriminative touch
  2. Proprioception (body position and motion)
  3. Nociception (pain and itch)
  4. Temperature
  5. Visceral function
- Senses external objects contacting the body
- Provides self-awareness of our bodies

Dorsal root ganglion neurons mediate somatic sensation



- Detect mechanical, thermal or chemical signals
- Transduce stimulus energy into electrical signals
- Encode depolarization as a spike train
- Transmit encoded information to spinal cord or brainstem

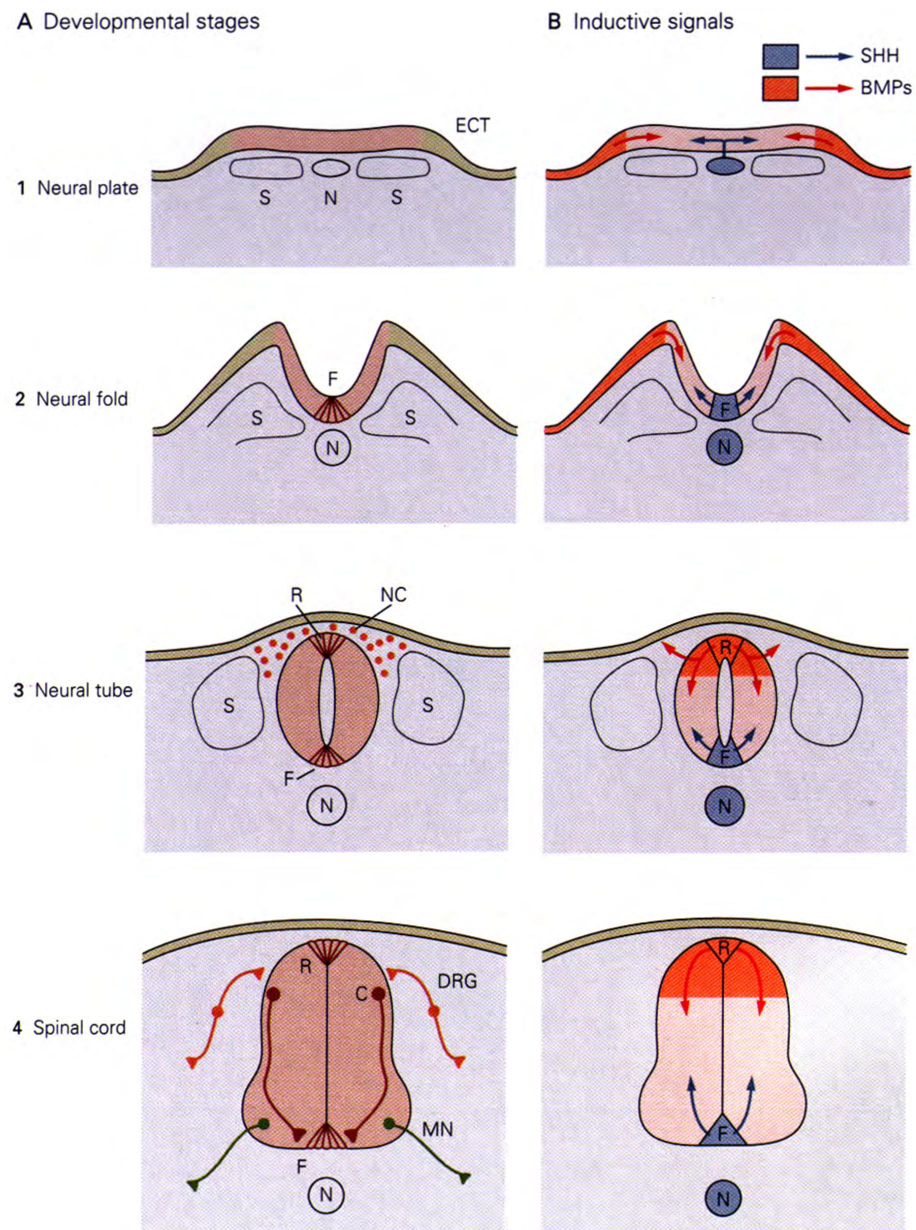
Common properties of DRG neurons

- Sensory transduction occurs in the nerve endings, not in the DRG or trigeminal cell bodies
- Sensory modality determined by the receptor proteins expressed in the nerve terminals, and anatomical structures enclosing these endings
- DRGs often express receptor proteins in their somas allowing transduction mechanisms to be studied *in vitro*

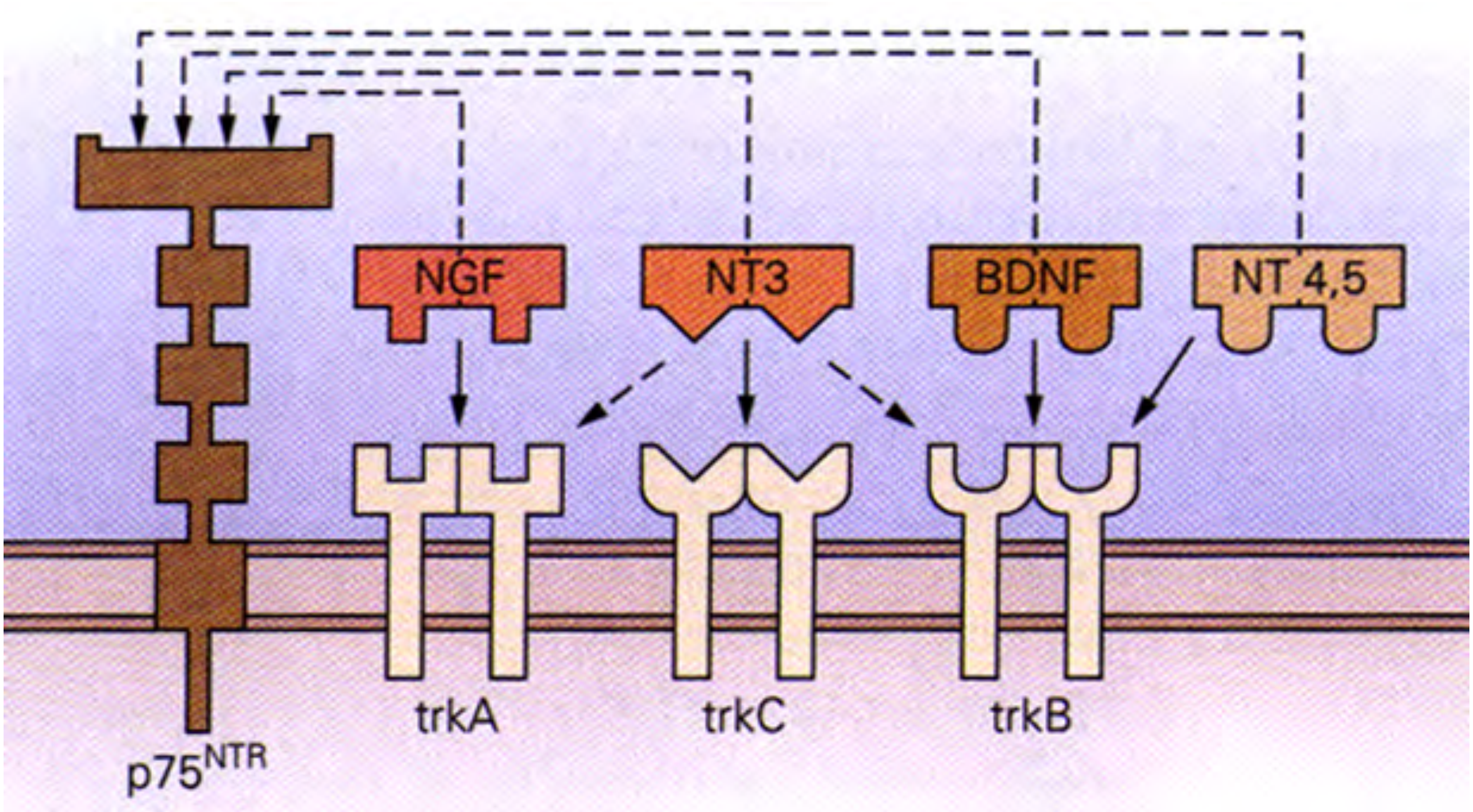
Dorsal root ganglion neurons differ in:

- Cell body *size*
- *Morphology* and sensitivity of nerve terminal
- *Sensations* mediated
- Body *region* innervated
- Axon *conduction velocity* and fiber diameter
- Spinal and brainstem *termination sites*
- Ascending *pathways* to higher brain centers
- Sensitivity to *neurotrophins* during development

DRGs develop from neural crest cells

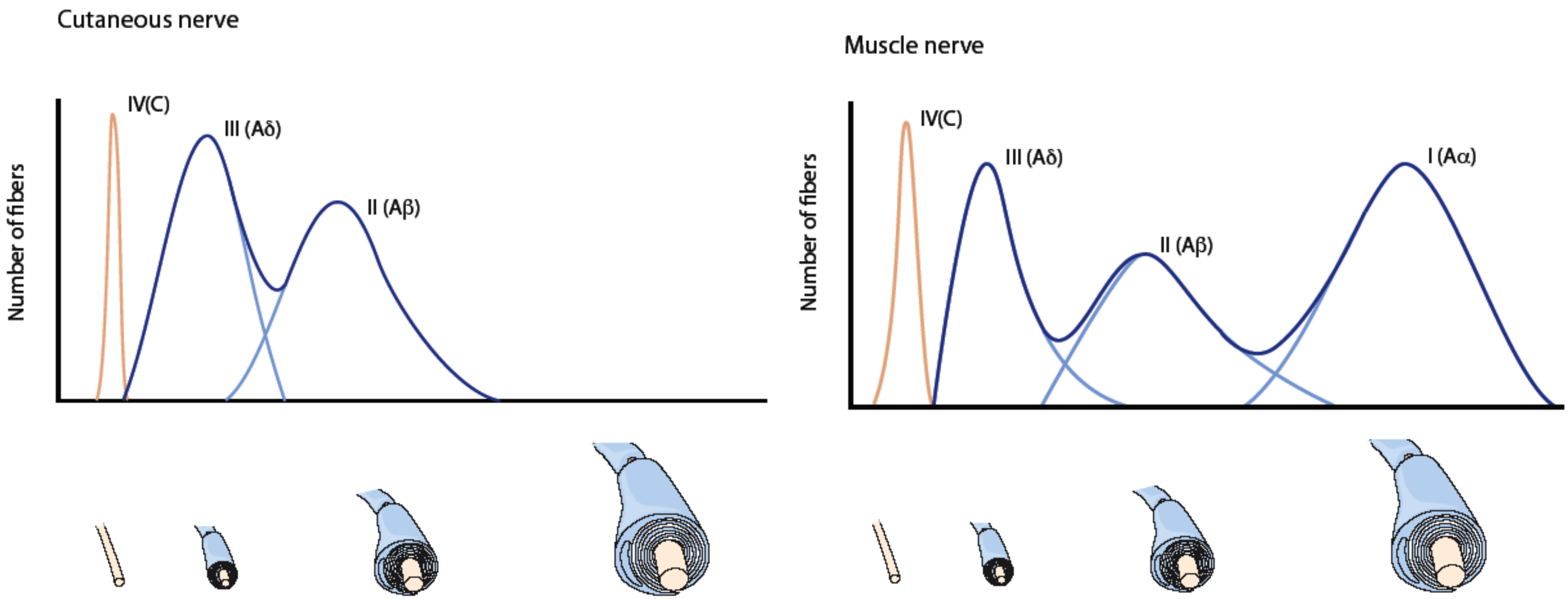


DRGs express neurotrophin receptors



- trkA: free nerve endings (pain and temperature)
- trkB: mechanoreceptors in skin, muscle, joints
- trkC: muscle spindles and tendon organs

Fiber diameter profile for different modalities



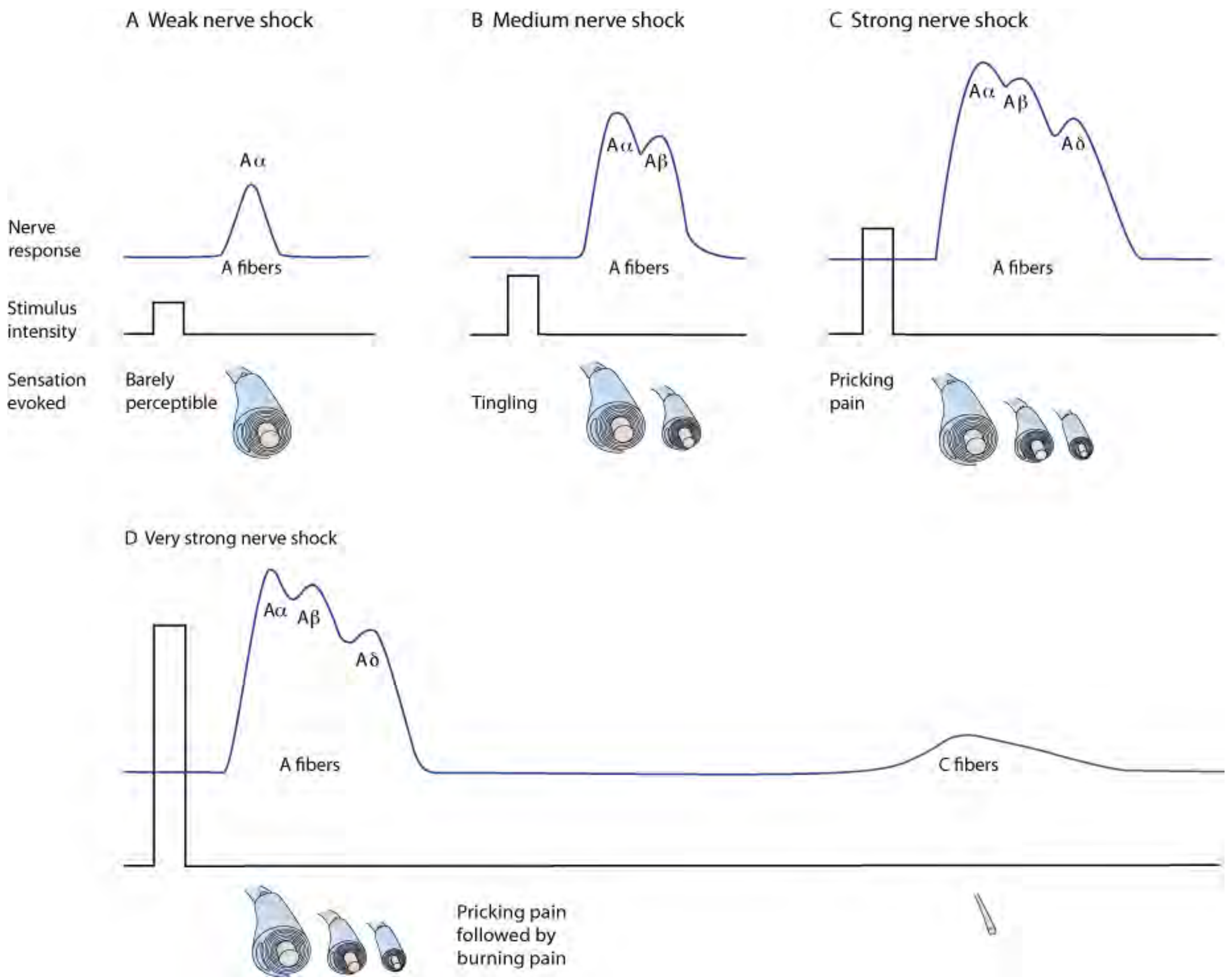
Cutaneous nerve:

Axon diameter (µm)	1	5	12	20
Conduction velocity (m/s)	6	30	72	120

Muscle nerve:

Axon diameter (µm)	1	5	12	20
Conduction velocity (m/s)	6	30	72	120

Compound action potential reflects whole nerve activity



Conduction velocity classification

Aα	72–120 m/s	α motor neurons to muscle Group I muscle sensory Cutaneous mechanoreceptors
Aβ	30–96 m/s	Cutaneous mechanoreceptors Secondary muscle receptors
Aγ	12–48 m/s	γ motor neurons
Aδ	4–30 m/s	Group III sensory nerves
B	3–15 m/s	Autonomic preganglionics
C	0.5–2 m/s	Unmyelinated sensory nerves Autonomic postganglionics

The Sense of Touch

Jusepe de Ribera
c. 1615-16

Norton Simon Museum
Pasadena CA

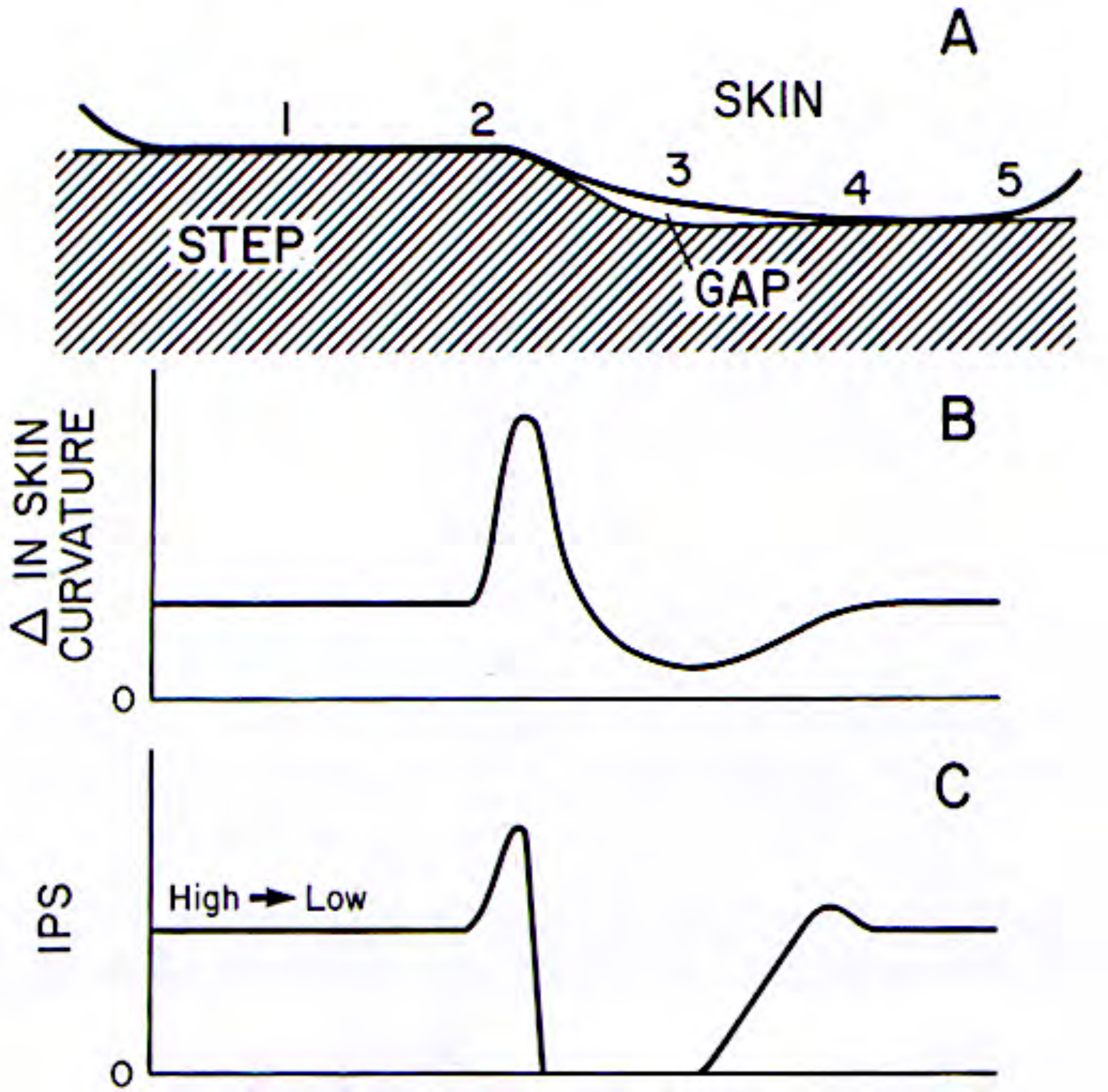
The sense of touch

- Touch is the special sense by which contact with the body is perceived in the conscious mind
- Touch allows us to recognize objects held in the hand and use them as tools
- Touch enables the blind to perceive the three dimensional form of objects, and to read Braille with their fingers
- Touch guides skilled hand movements of the surgeon, the sculptor, the musician, the pitcher, and the chef
- Touch is mediated by mechanoreceptors in the skin

Properties coded by the sense of touch

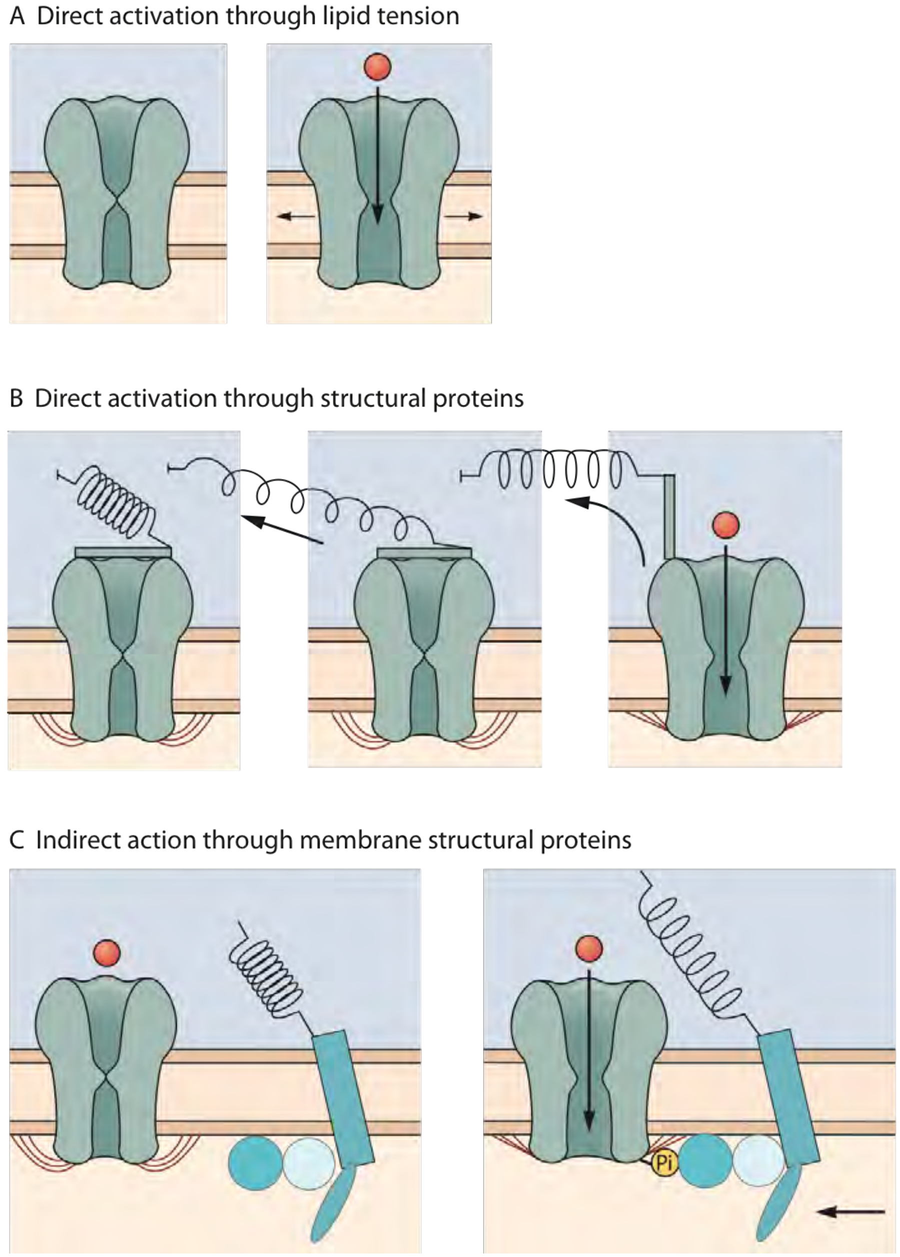
- Spatial dimensions (size, shape, weight)
- Surface compliance (hard or soft)
- Surface texture (smooth or rough, regular or irregular)
- Temperature (hot, warm, cool, cold)
- Motion (active or passive, velocity, direction)
- Cognitive function (object recognition)

The sense of touch is mediated by skin indentation



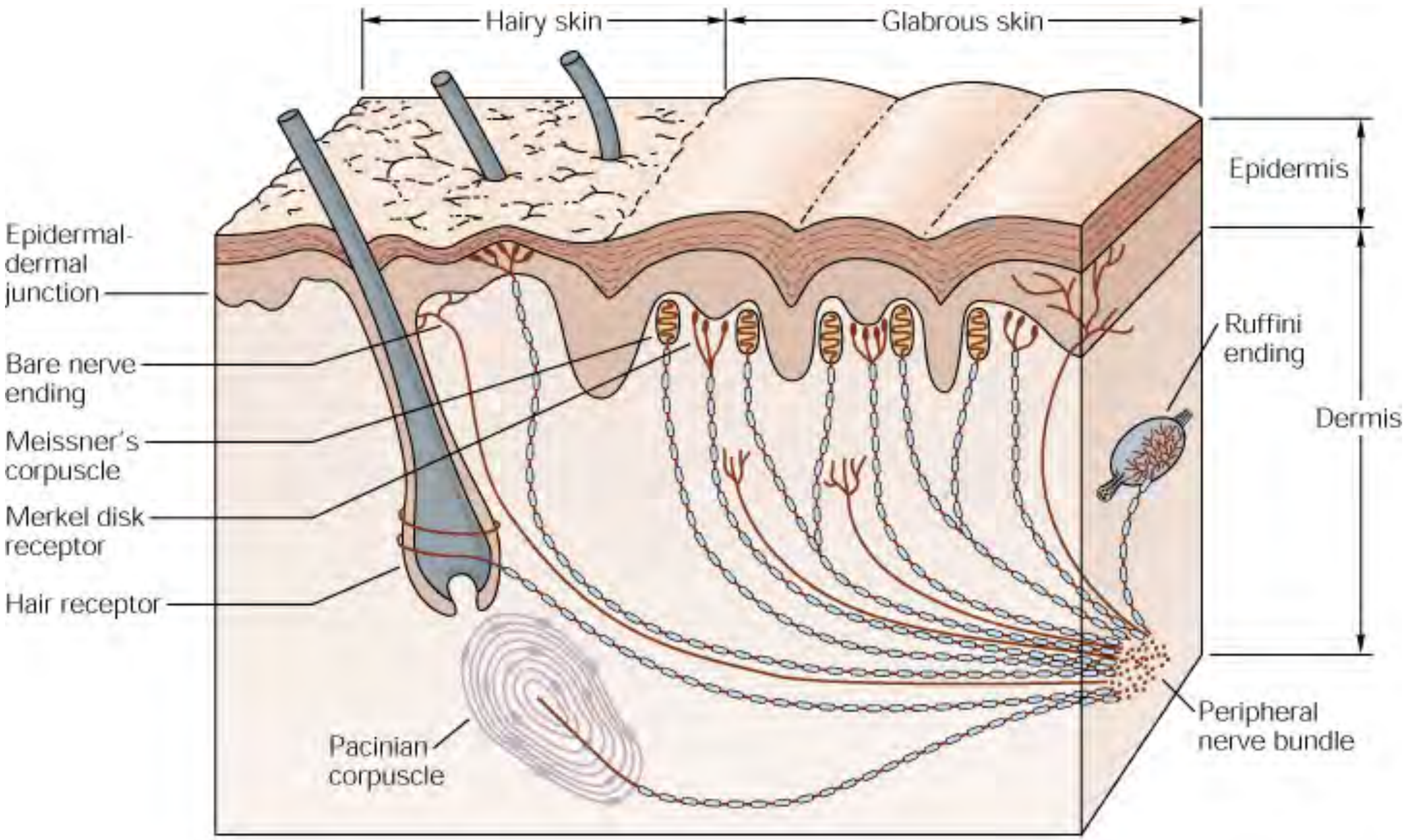
LaMotte RH, Srinivasan MA. *J Neurophysiol* 1987

Mechanoreceptors detect tissue deformation

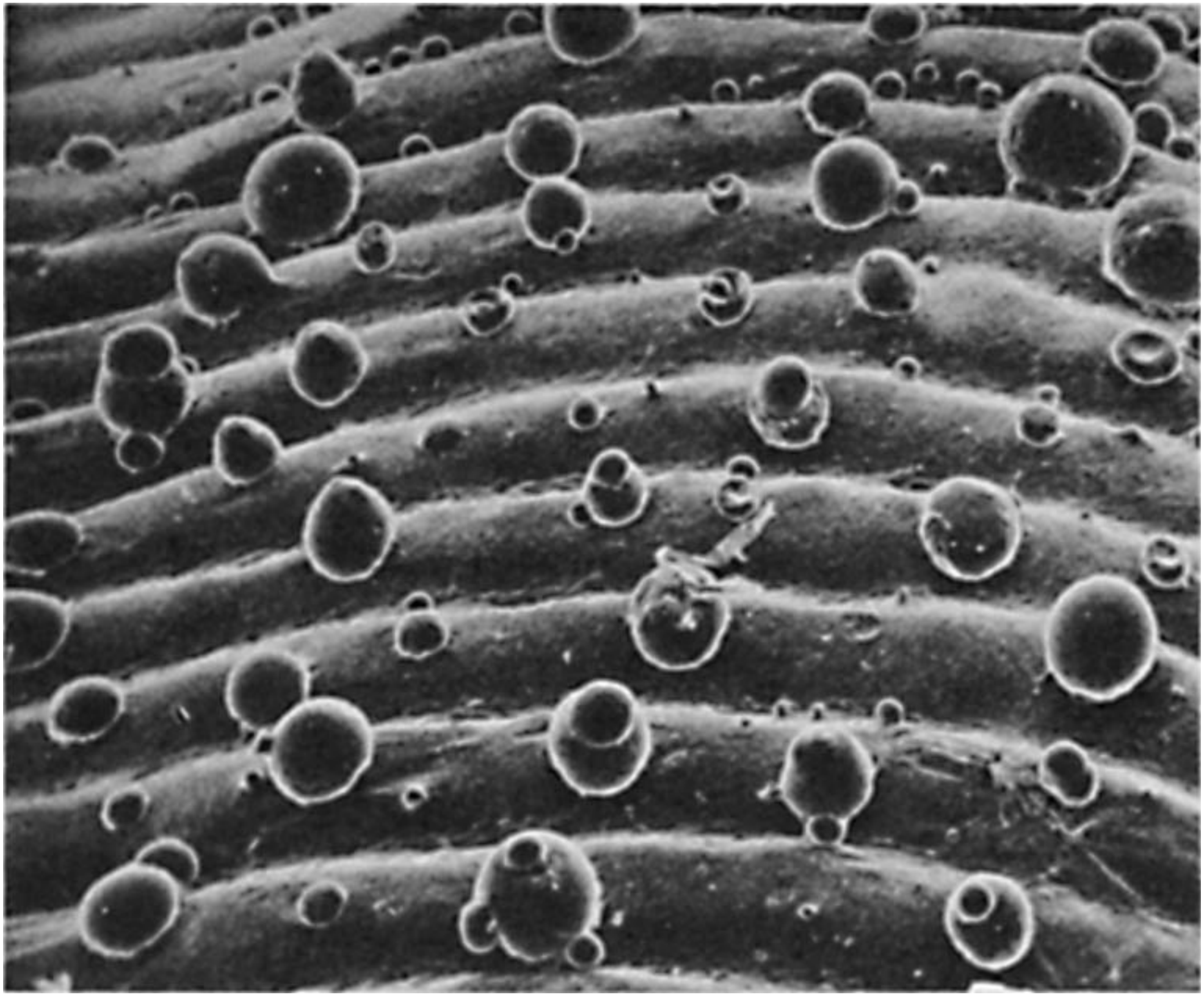


Lin S-Y, Corey DP.
Curr Opin Neurobiol 2005

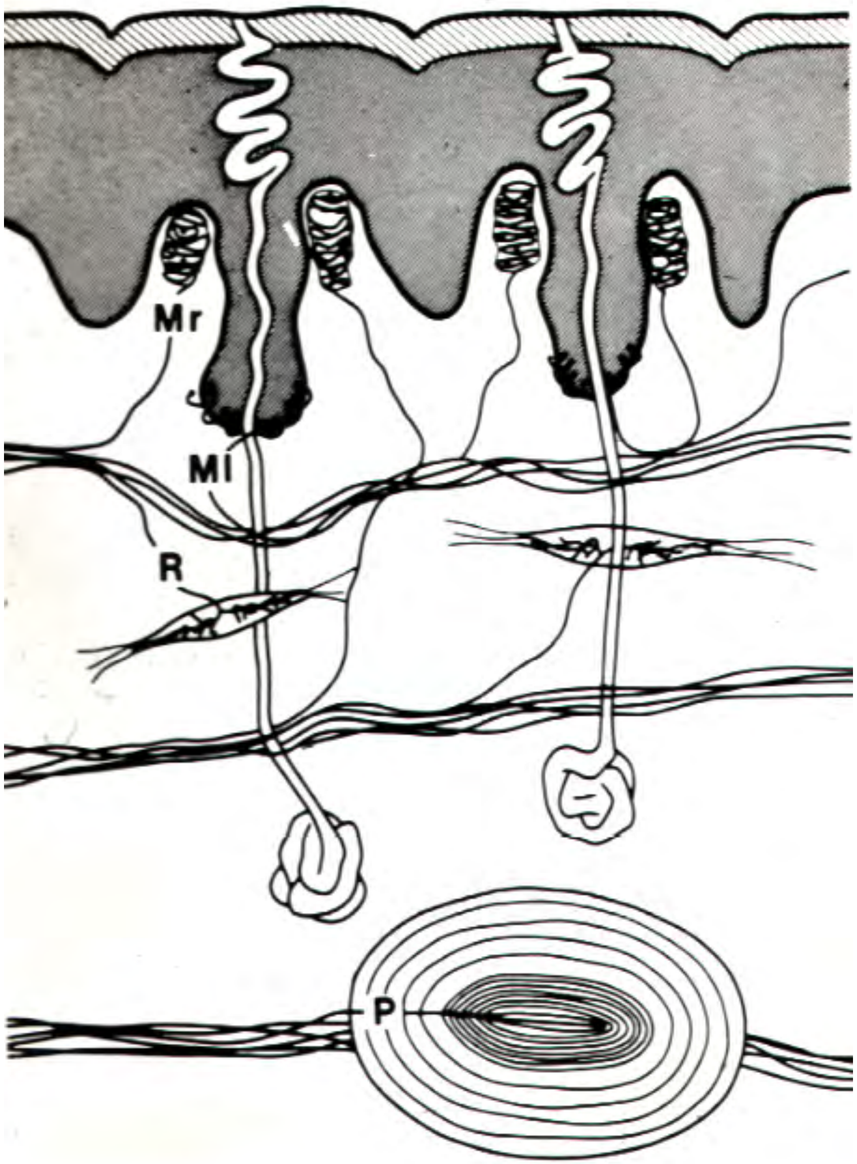
Multiple receptor types in the skin



Scanning EM of fingerprint ridges in glabrous skin



Four types of mechanoreceptors in glabrous skin



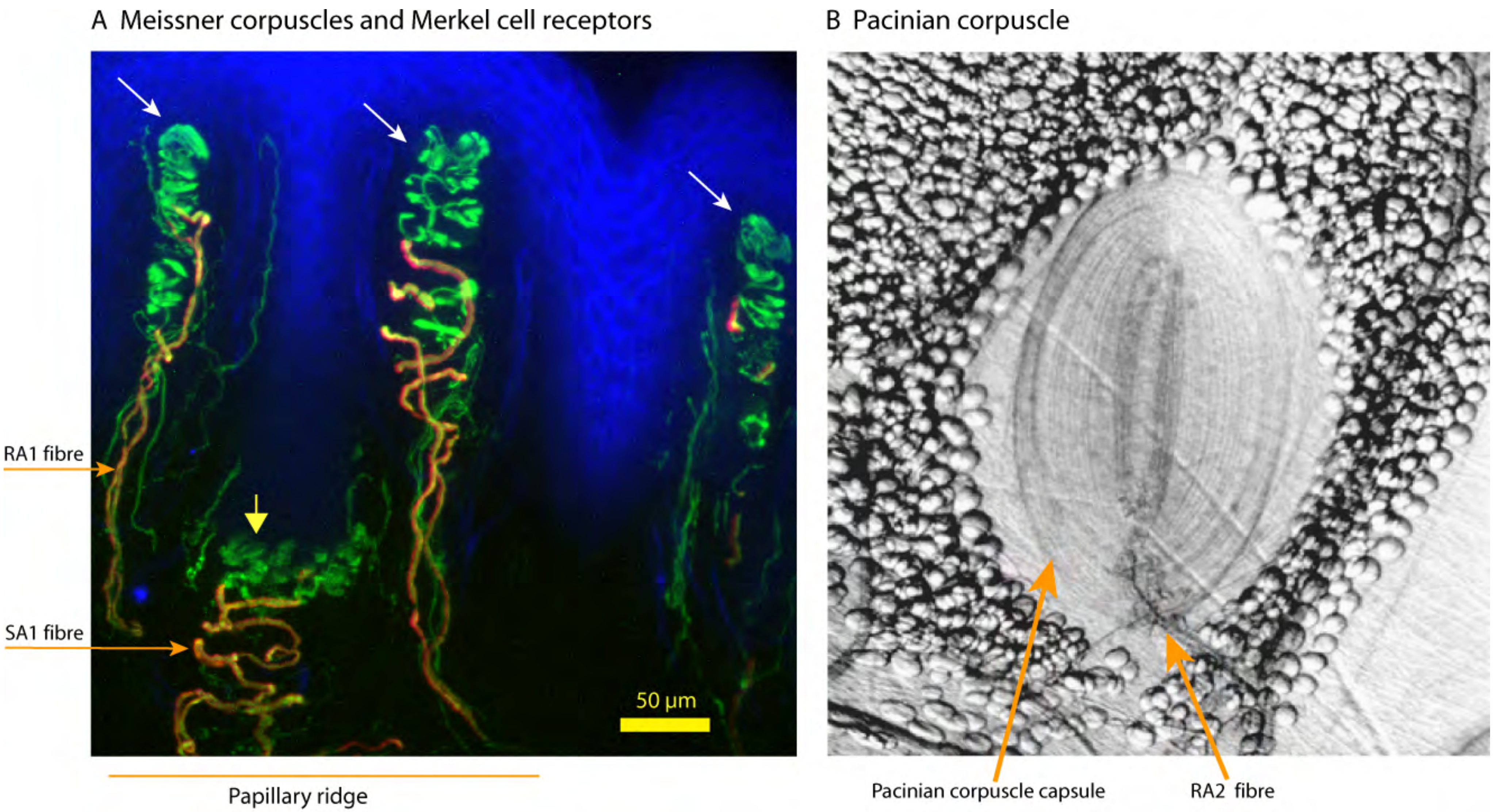
Meissner’s corpuscles (RA1)

Merkel cells (SA1)

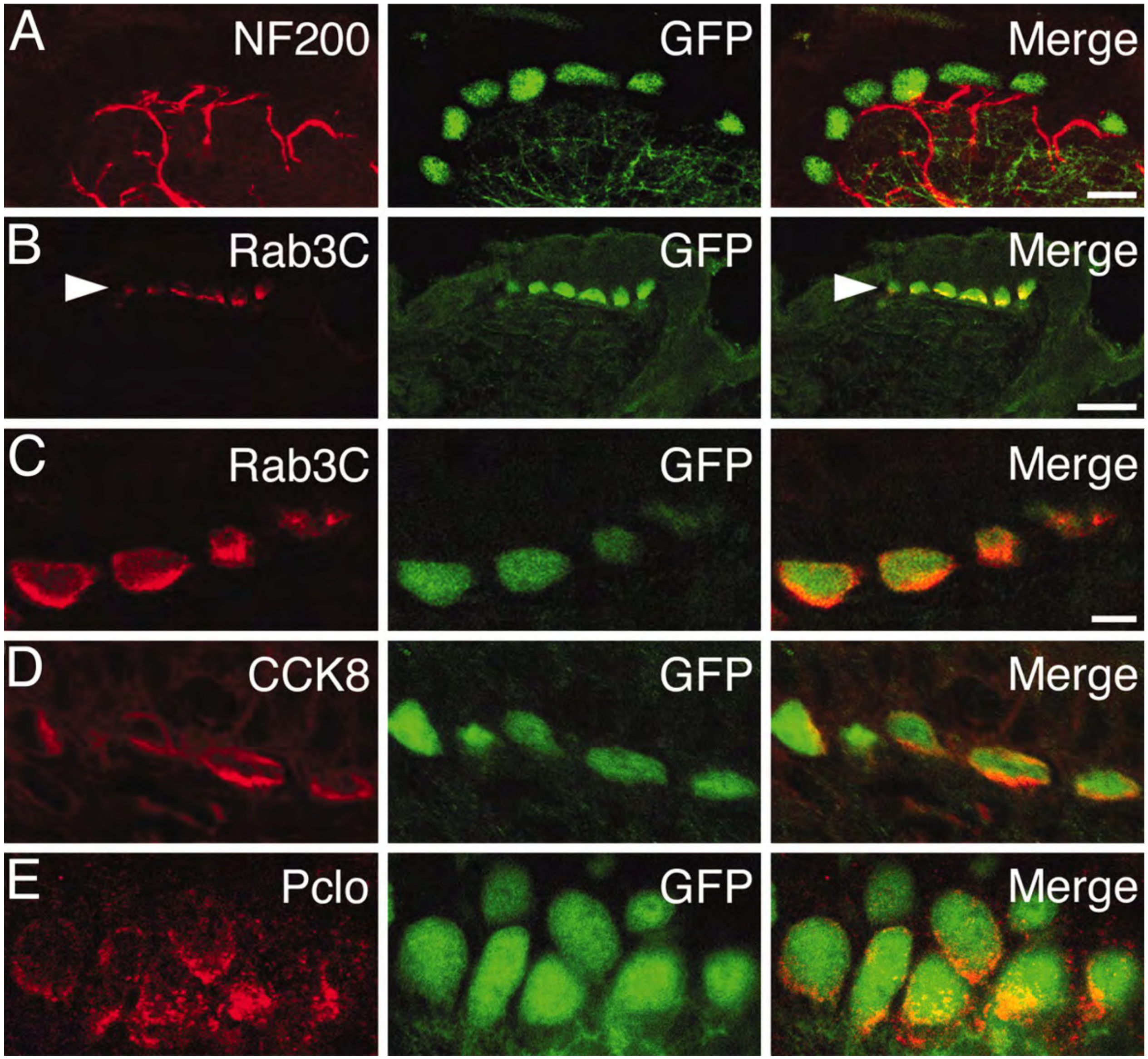
Ruffini endings (SA2)

Pacinian corpuscles (RA2)

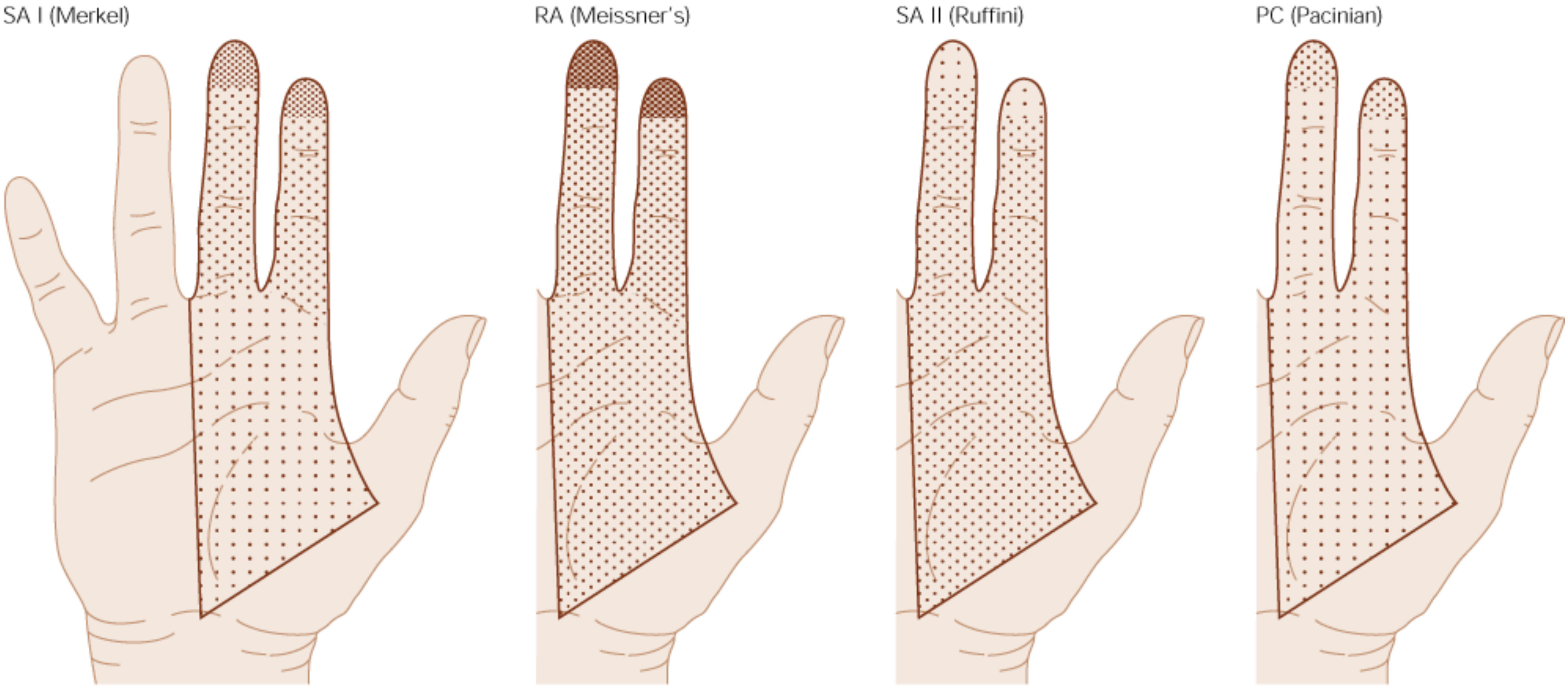
Touch receptors in the glabrous skin



SA1 fibers innervate clusters of Merkel cells



Receptor density in glabrous skin



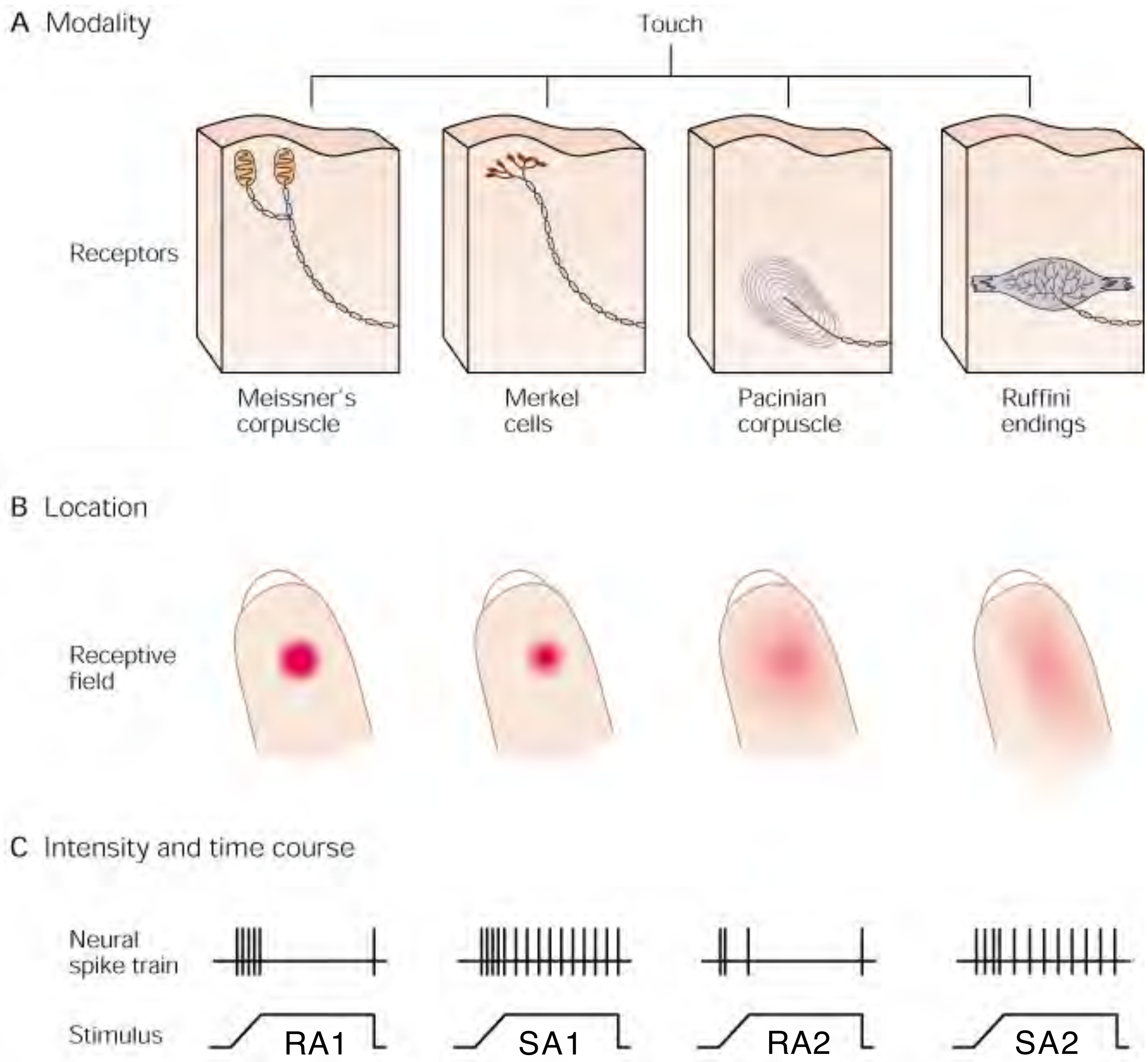
- Fingertip
  - RA = 141 /cm^2 SA I = 70 /cm^2
  - PC = 21 /cm^2 SA II = 9 /cm^2
- Palm
  - RA = 25 /cm^2 SA I = 8 /cm^2
  - PC = 9 /cm^2 SA II =16 /cm^2

Johansson RS, Vallbo ÅB. *J Physiol* 1979

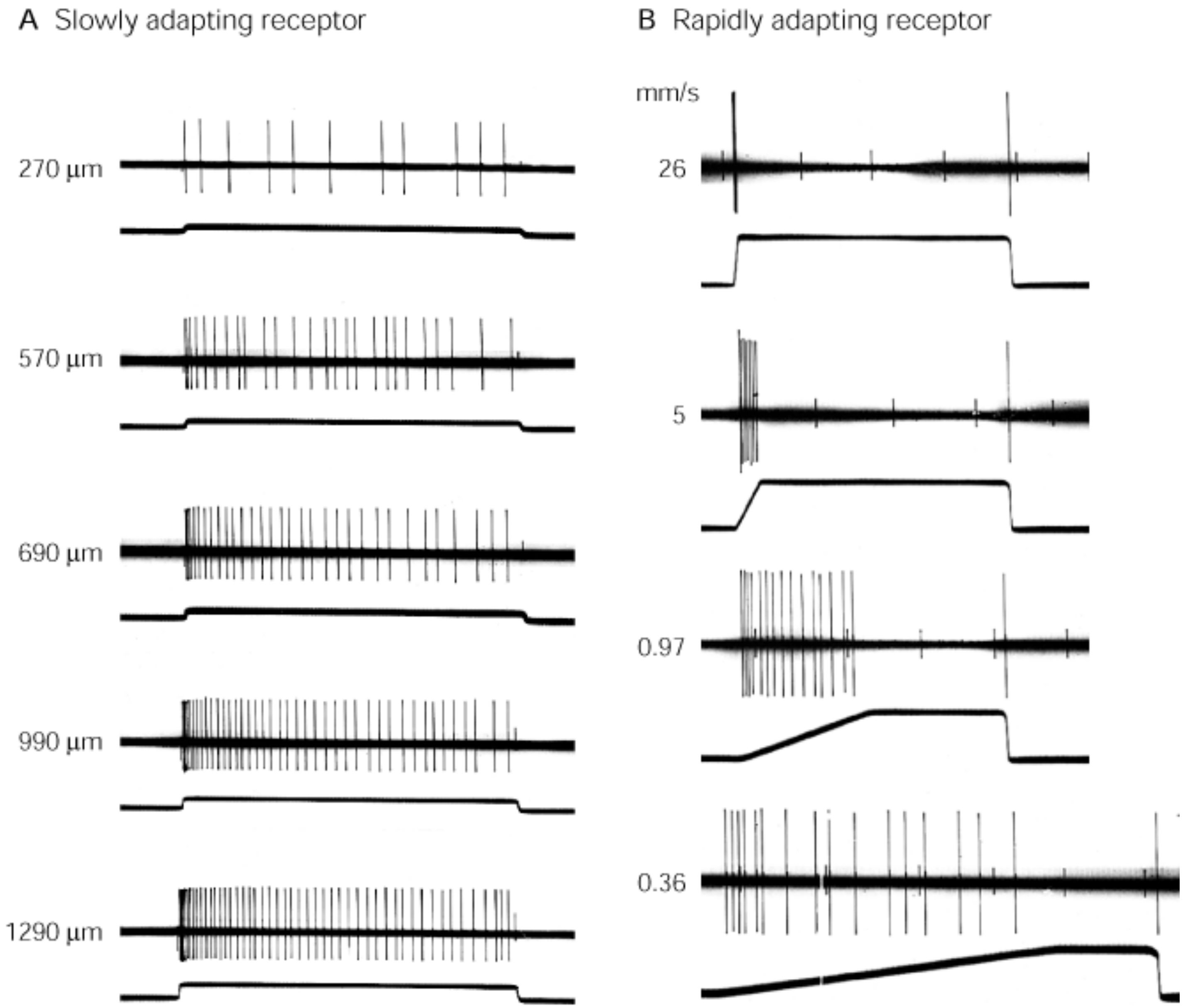
Why have multiple touch receptors?

- Specialize for dynamic and static sensitivity
  - Motion sensors (RA1 and RA2)
  - Pressure sensors (SA1 and SA2)
- Different sensory thresholds extend range of intensities encoded (RA2<RA1<SA1<SA2)
- Different receptive field areas encode fine (RA1 and SA1) and broad (RA2 and SA2) spatial information

Phasic and tonic responses to touch

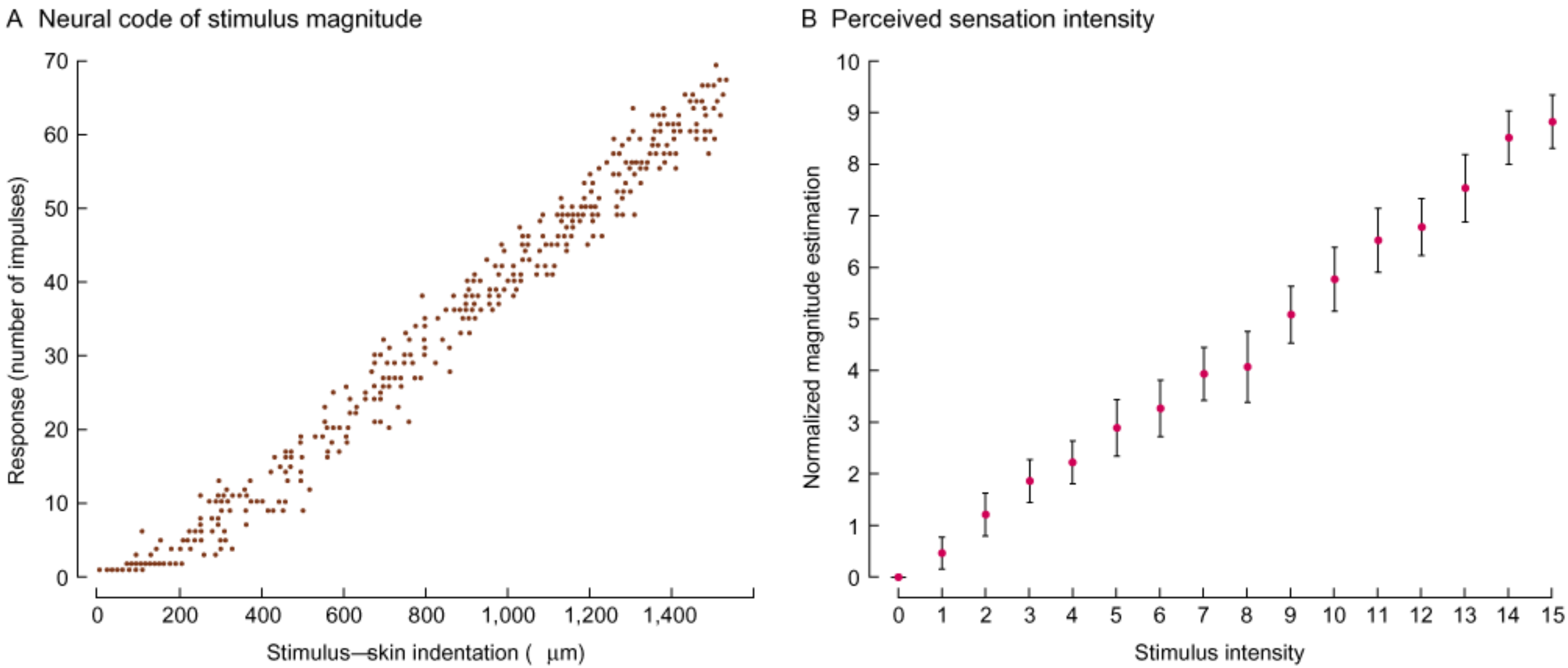


Slow and rapid adaptation of touch receptors



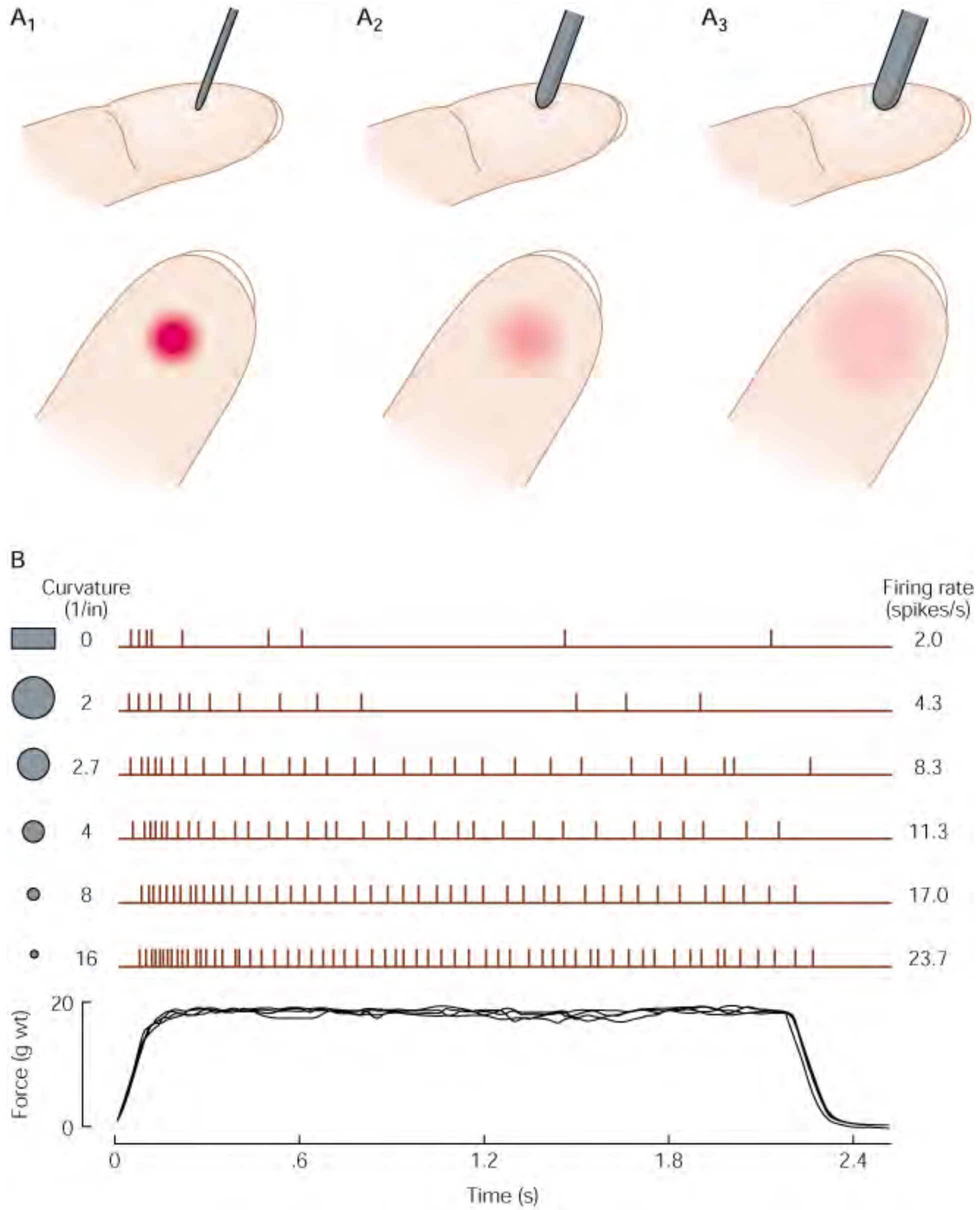
Mountcastle VB, et al. 1966; Talbot WH, et al. *J Neurophysiol* 1968

Neural firing rate codes stimulus intensity



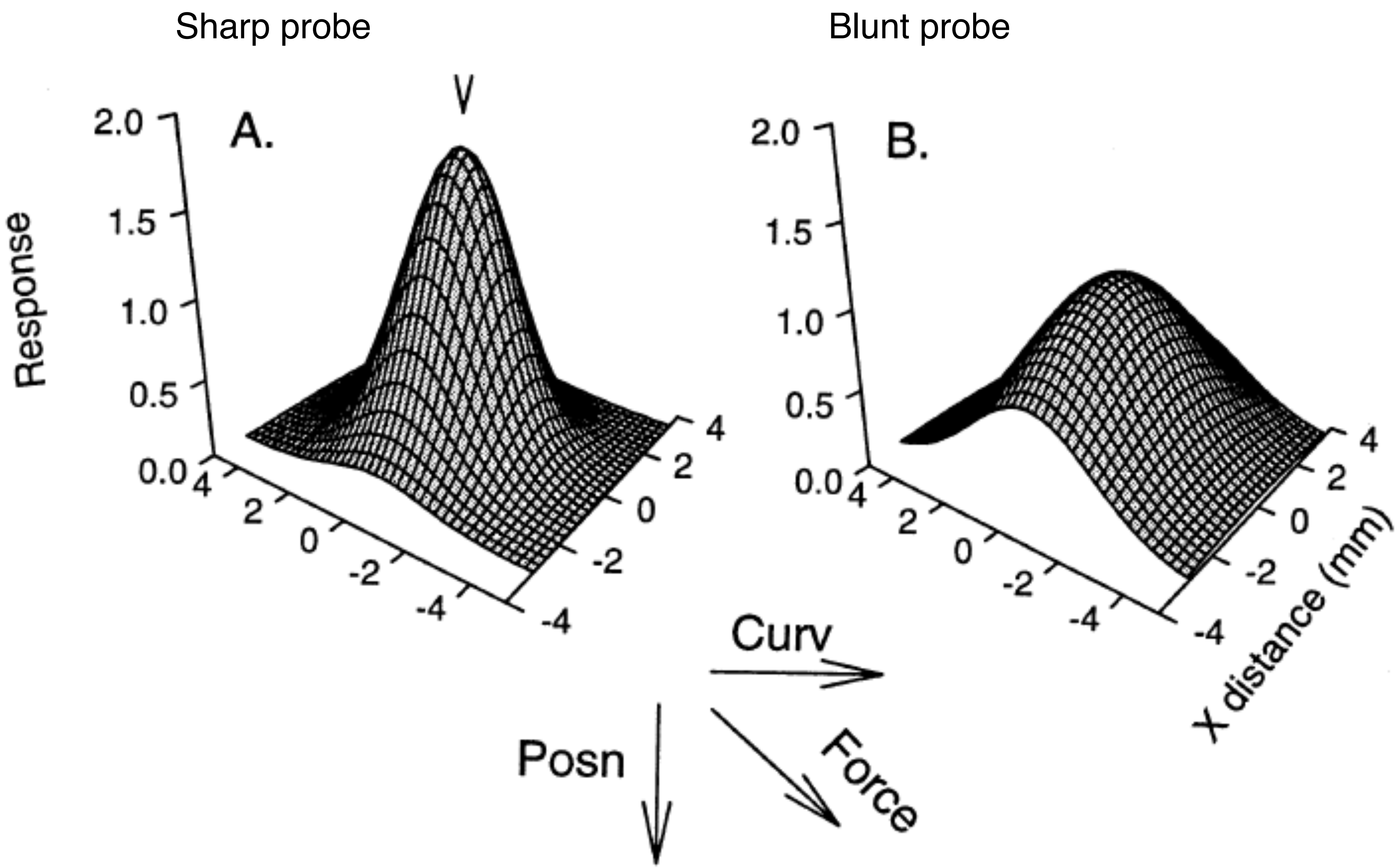
Mountcastle VB, et al. 1966

Merkel cells (SA1 fibers) signal shape and pressure



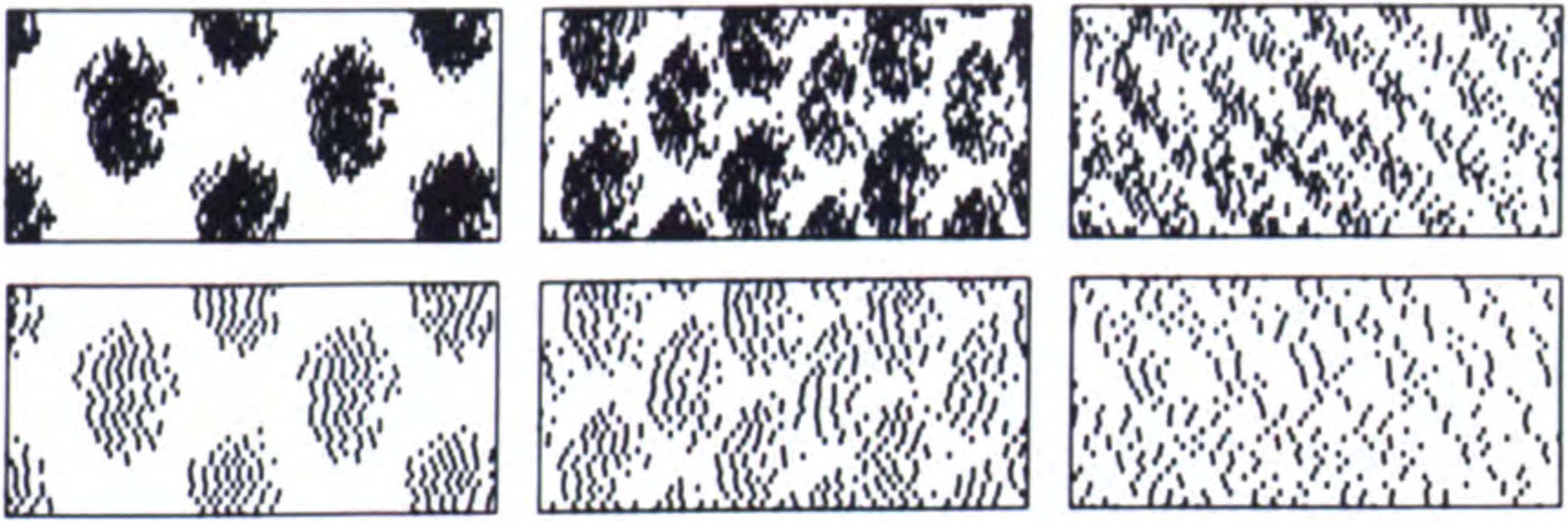
Srinivasan MA, LaMotte RH. 1991

Fingertip SA1 responses to object curvature



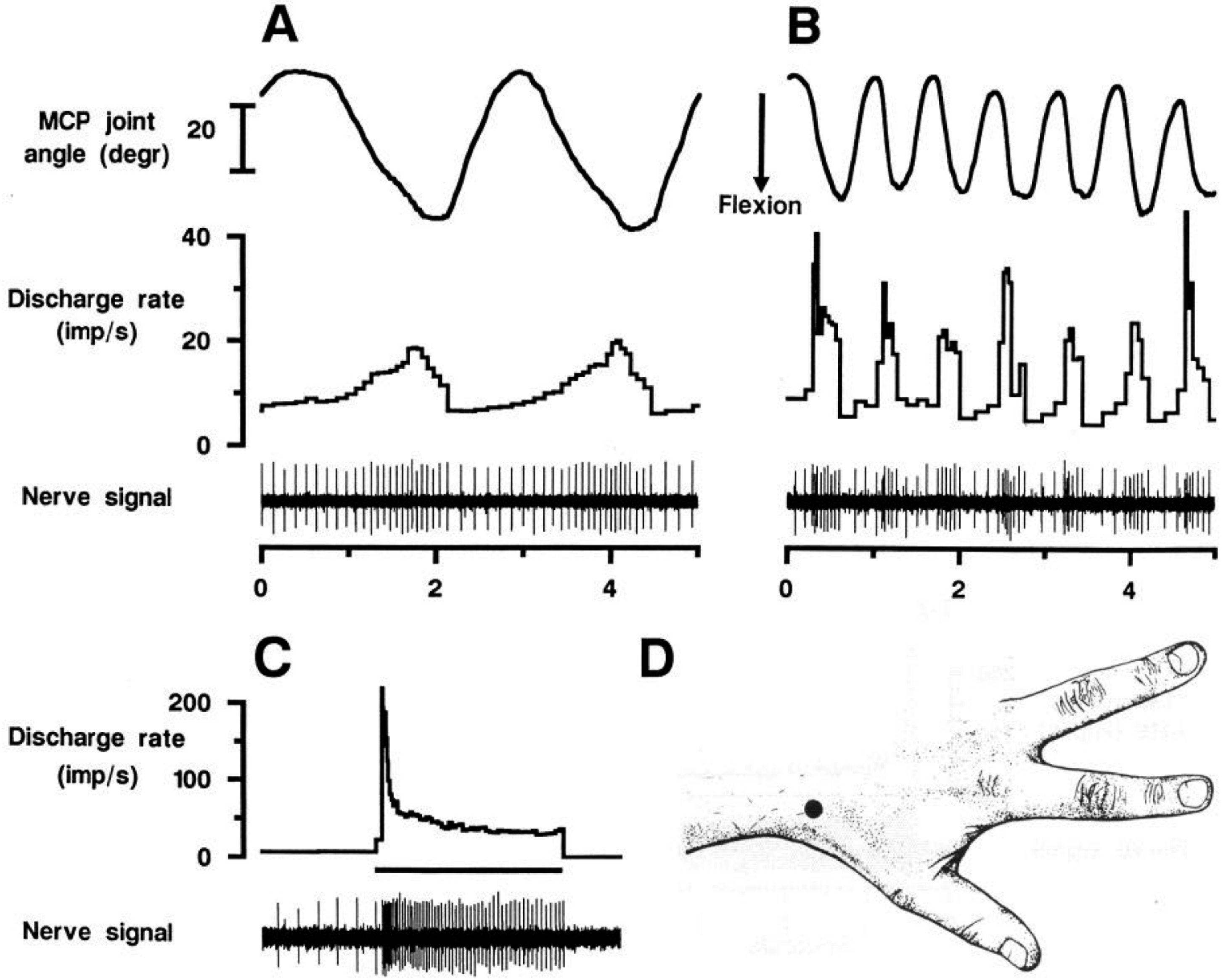
Goodwin AW, Wheat HE. *Ann Rev Neurosci* 2004

Merkel cells are used to read Braille dots



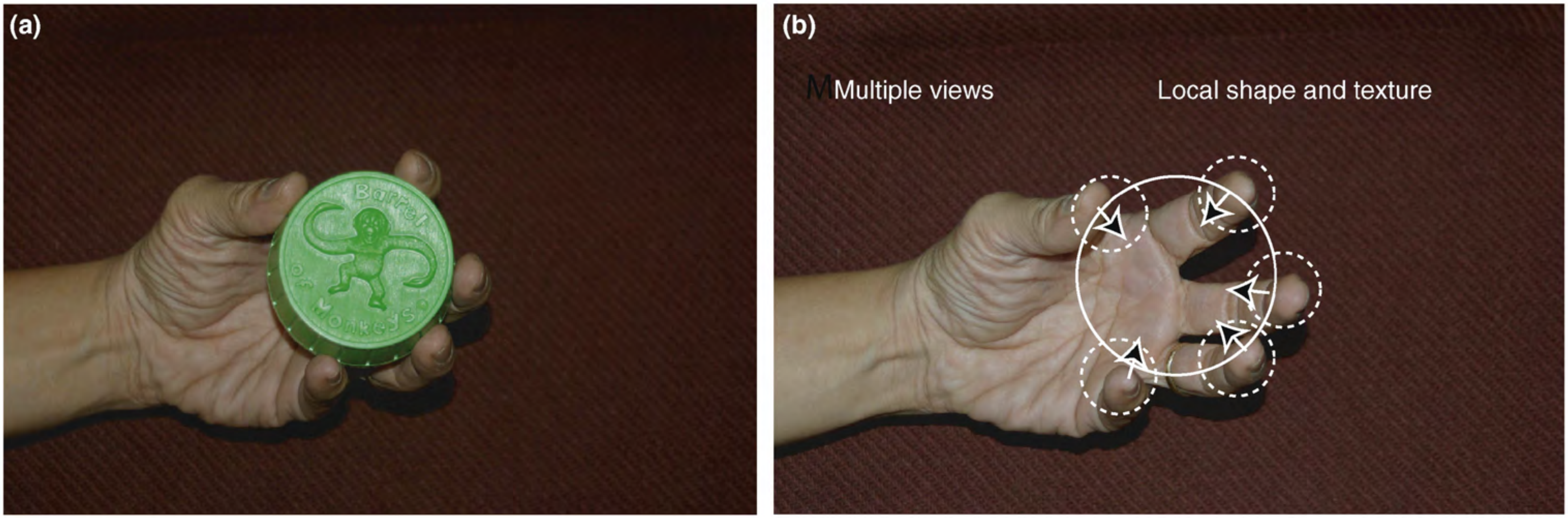
4.0 mm dot spacing   2.8 mm dot spacing   1.7 mm dot spacing

Ruffini endings (SA2 fibers) respond to skin stretch



Edin BB, Abbs JH. *J Neurophysiol* 1991

Hand posture and skin stretch codes object shape



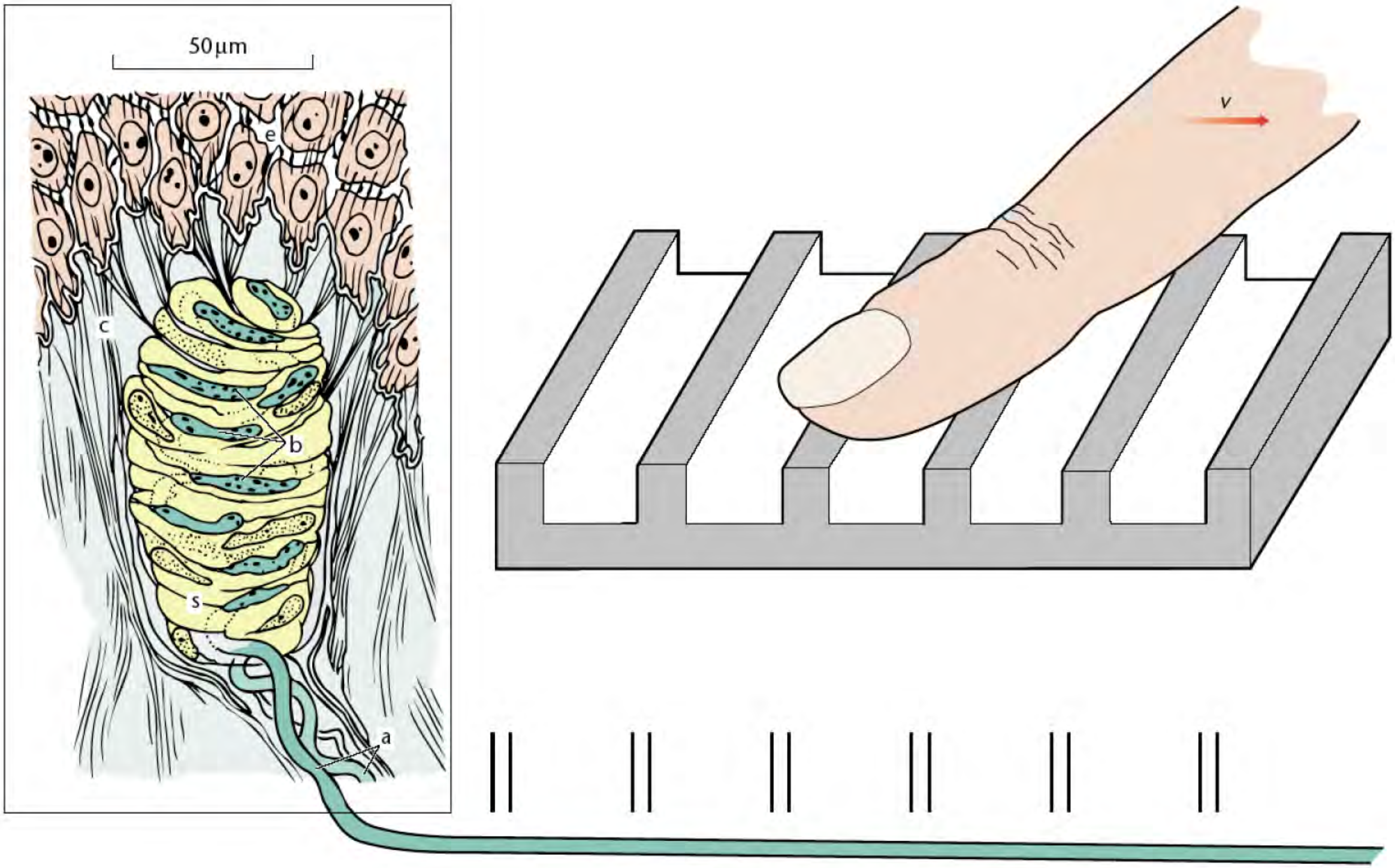
Current Opinion in Neurobiology

Hsiao SS (2008)

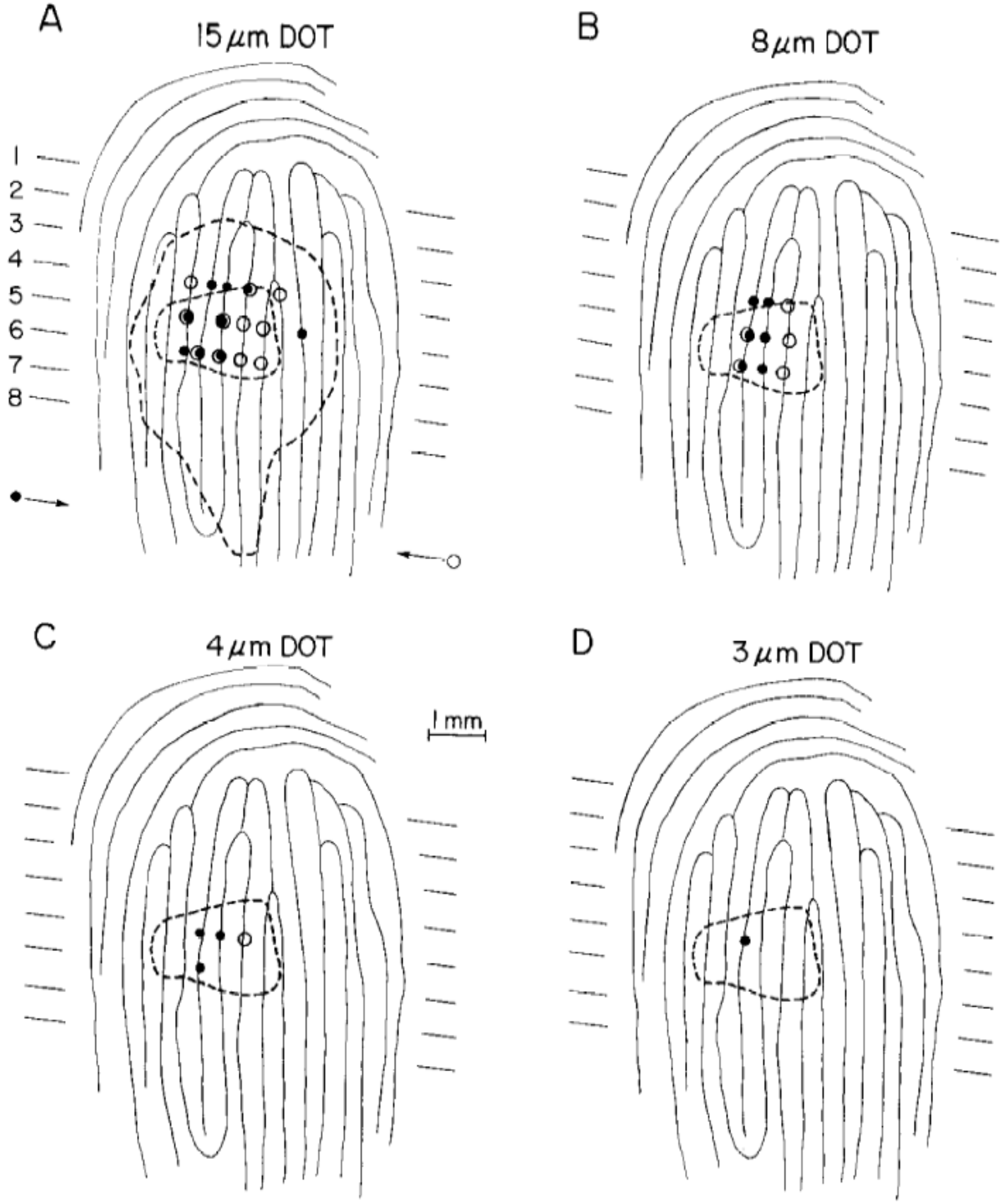
Slowly-Adapting Receptor Function

- Merkel cell (SA1 fiber):
  - Pressure, object weight
  - Precision grip force
  - Small object shape discrimination
  - Braille reading and texture discrimination
- Ruffini ending (SA2 fiber):
  - Whole hand grip
  - Hand posture and skin stretch
  - Large object shape discrimination

Meissner's corpuscles sense hand motion on surfaces

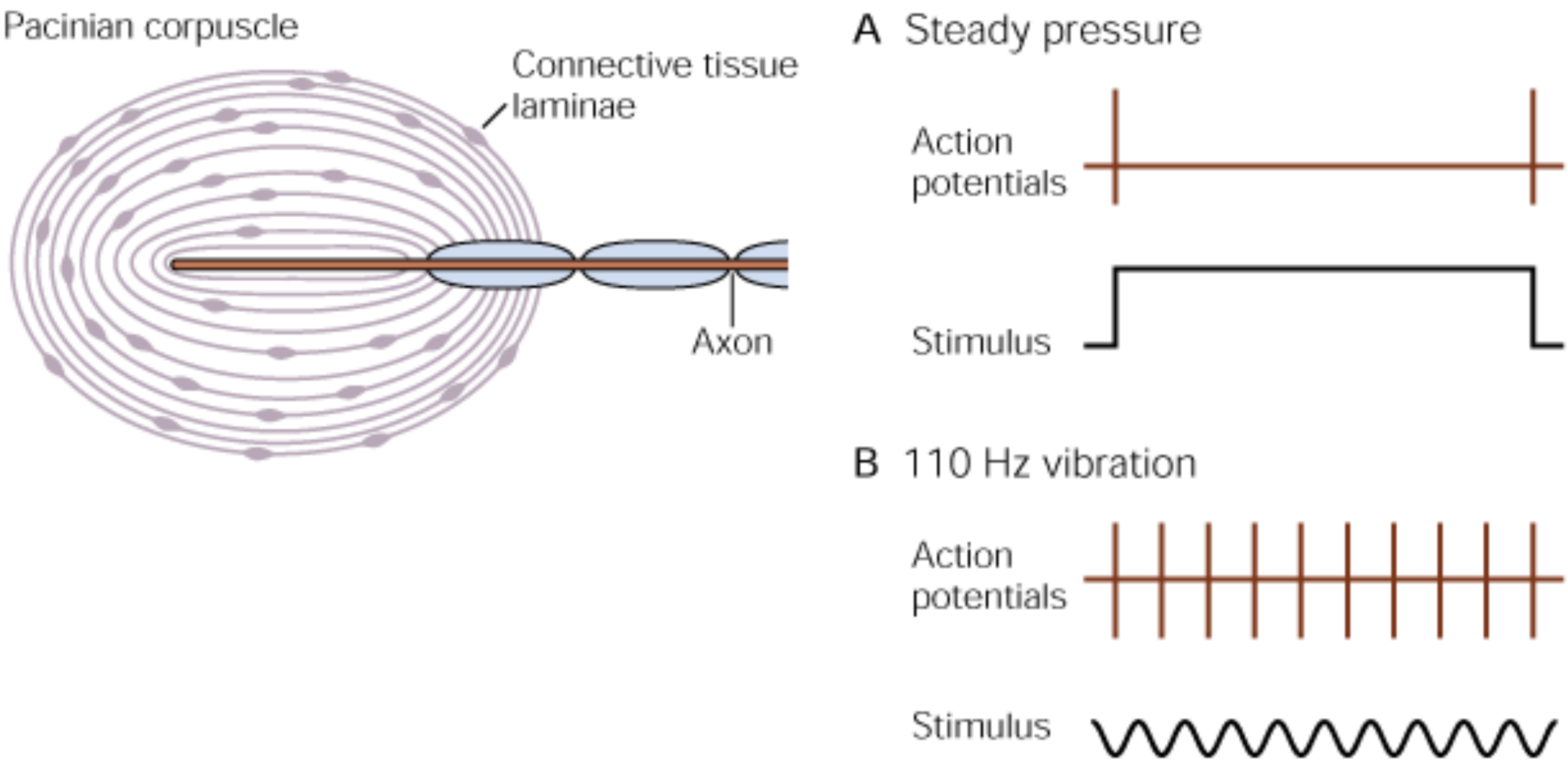


Meissner’s corpuscles detect motion of a small dot



LaMotte RH, Whitehouse J.
J Neurophysiol 1986

RA spike trains code motion and vibration



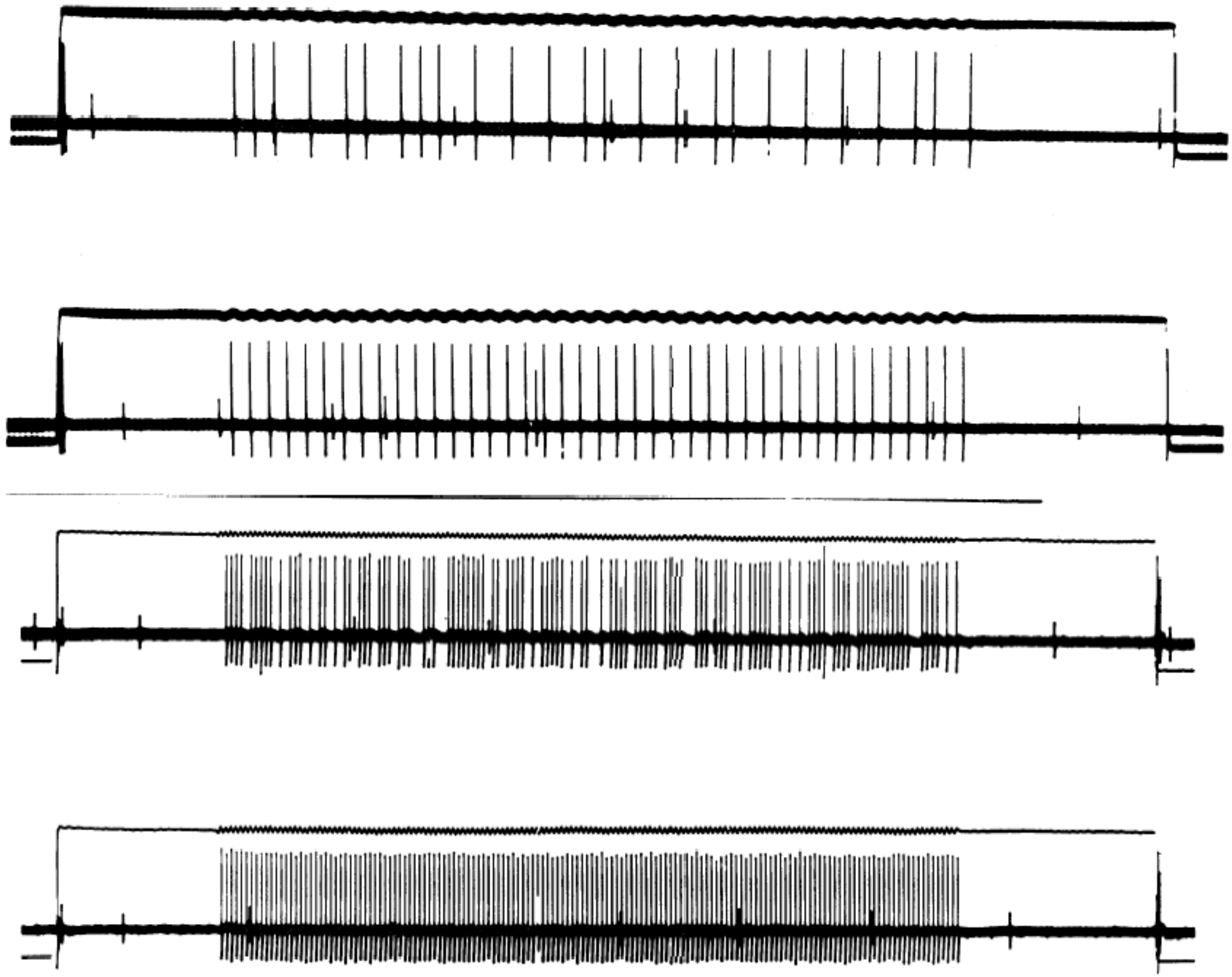
RA1 and RA2 fibers detect low and high frequencies

RA1 40 Hz

(Meissner)

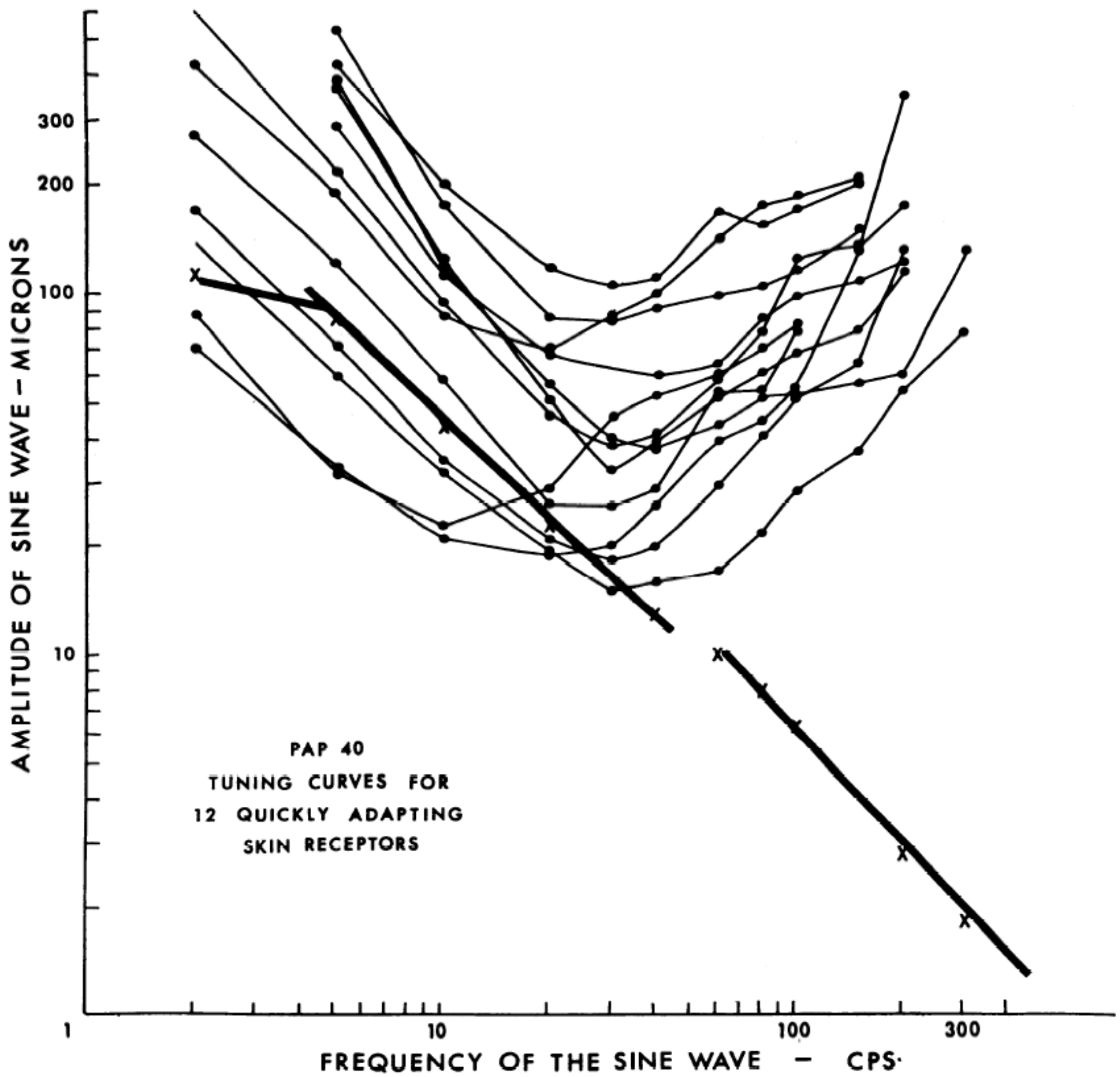
RA2 200 Hz

(Pacinian)



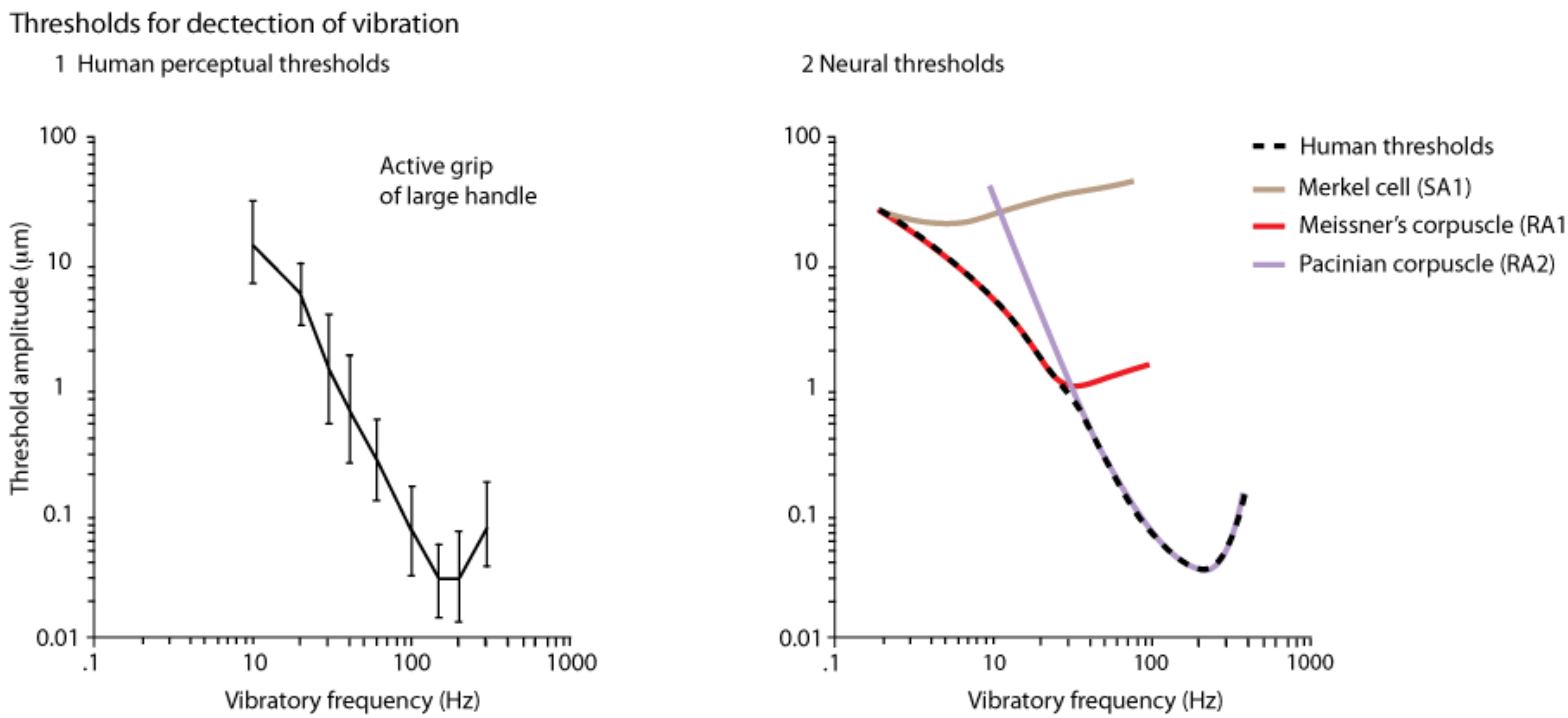
Tuning curves quantify vibratory threshold

RA1 fibers



Talbot WH, et al. *J Neurophysiol* 1968

Vibration thresholds are frequency dependent

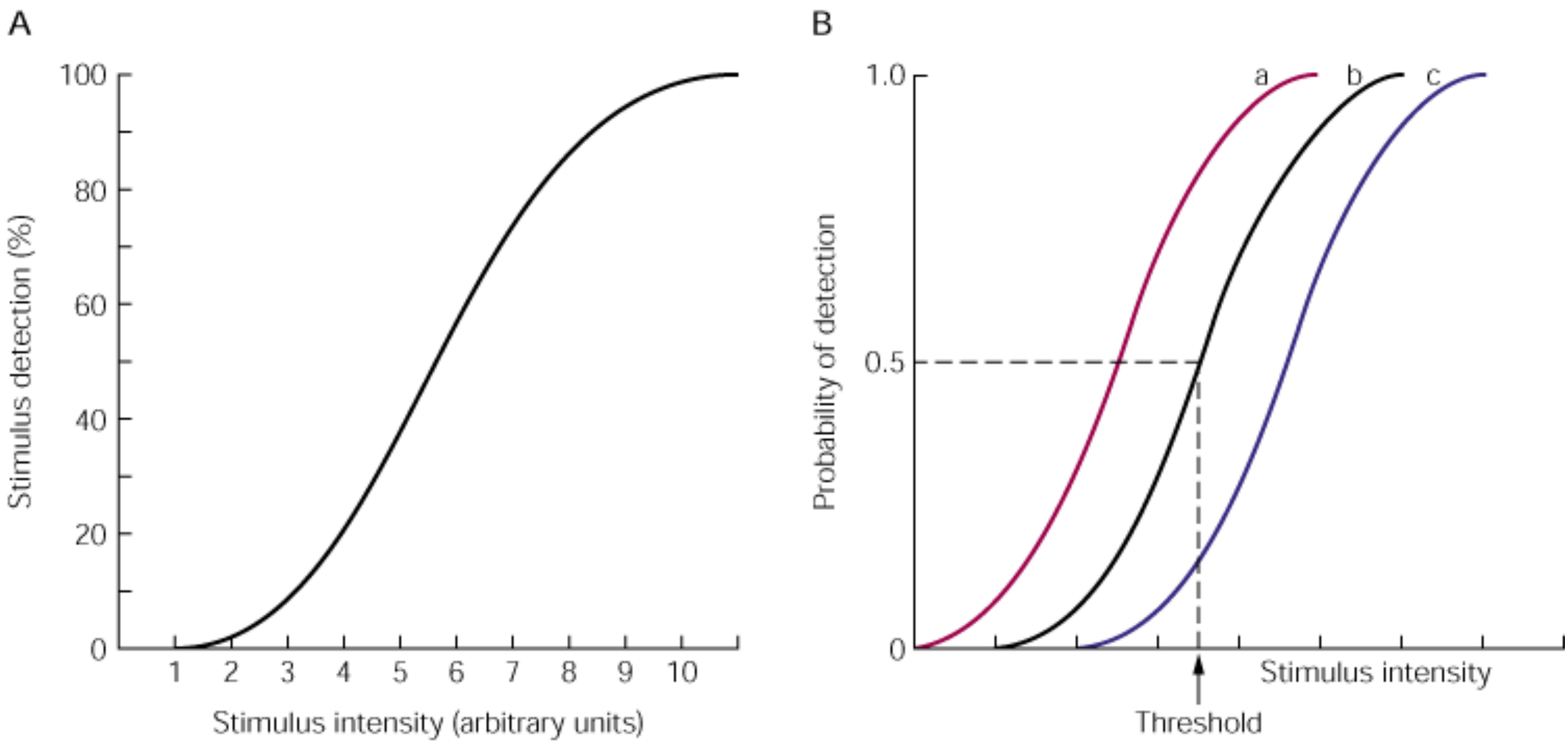


Talbot WH, et al. *J Neurophysiol* 1968

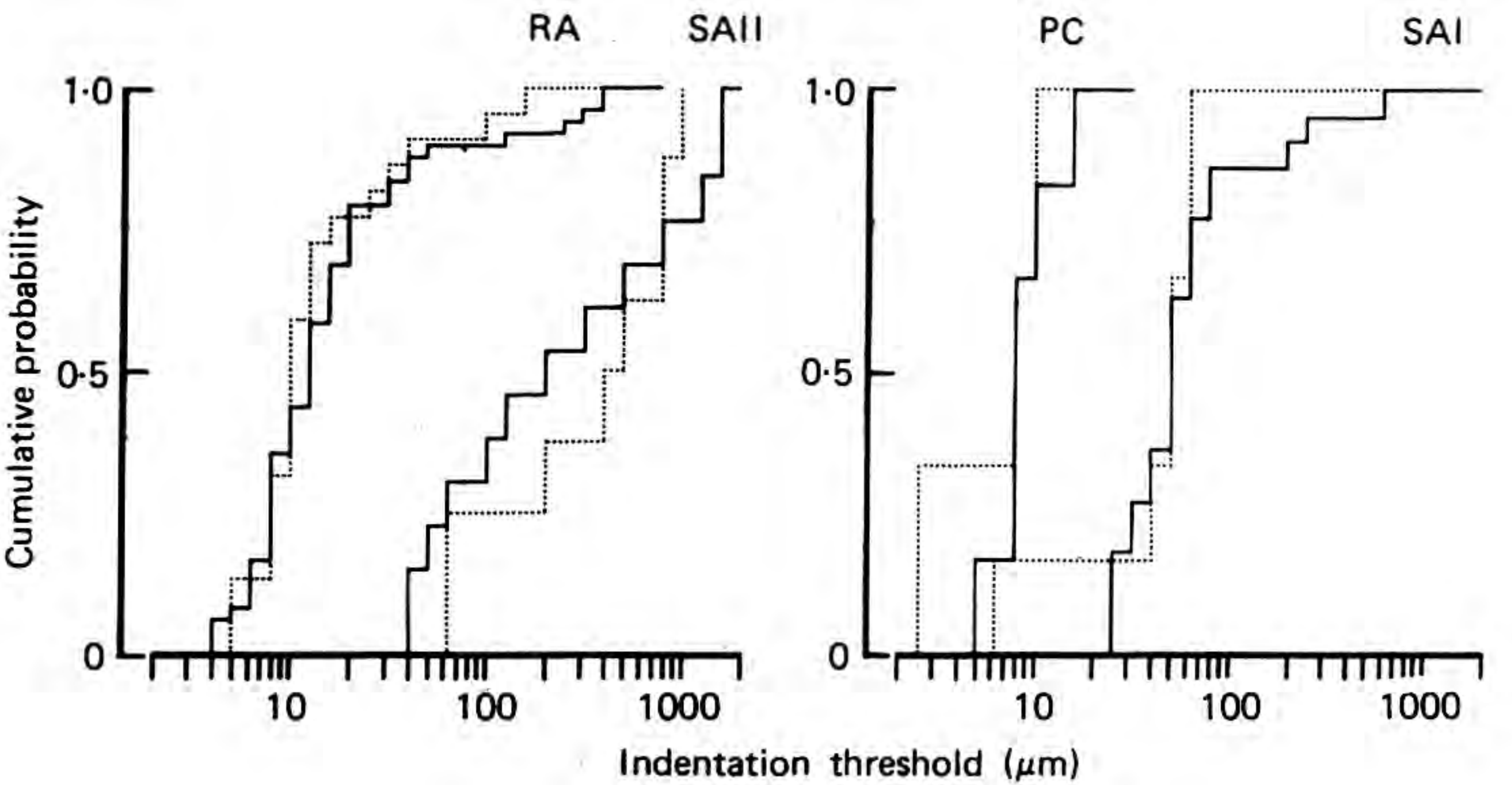
Rapidly-Adapting Receptor Function

- Meissner's corpuscle (RA1):
  - Motion
  - Texture
  - Edges
  - Flutter (low-frequency vibration)
- Pacinian corpuscle (RA2):
  - Vibration (tool use)
  - Contact and release

Threshold diversity extends dynamic range



Touch receptor thresholds differ

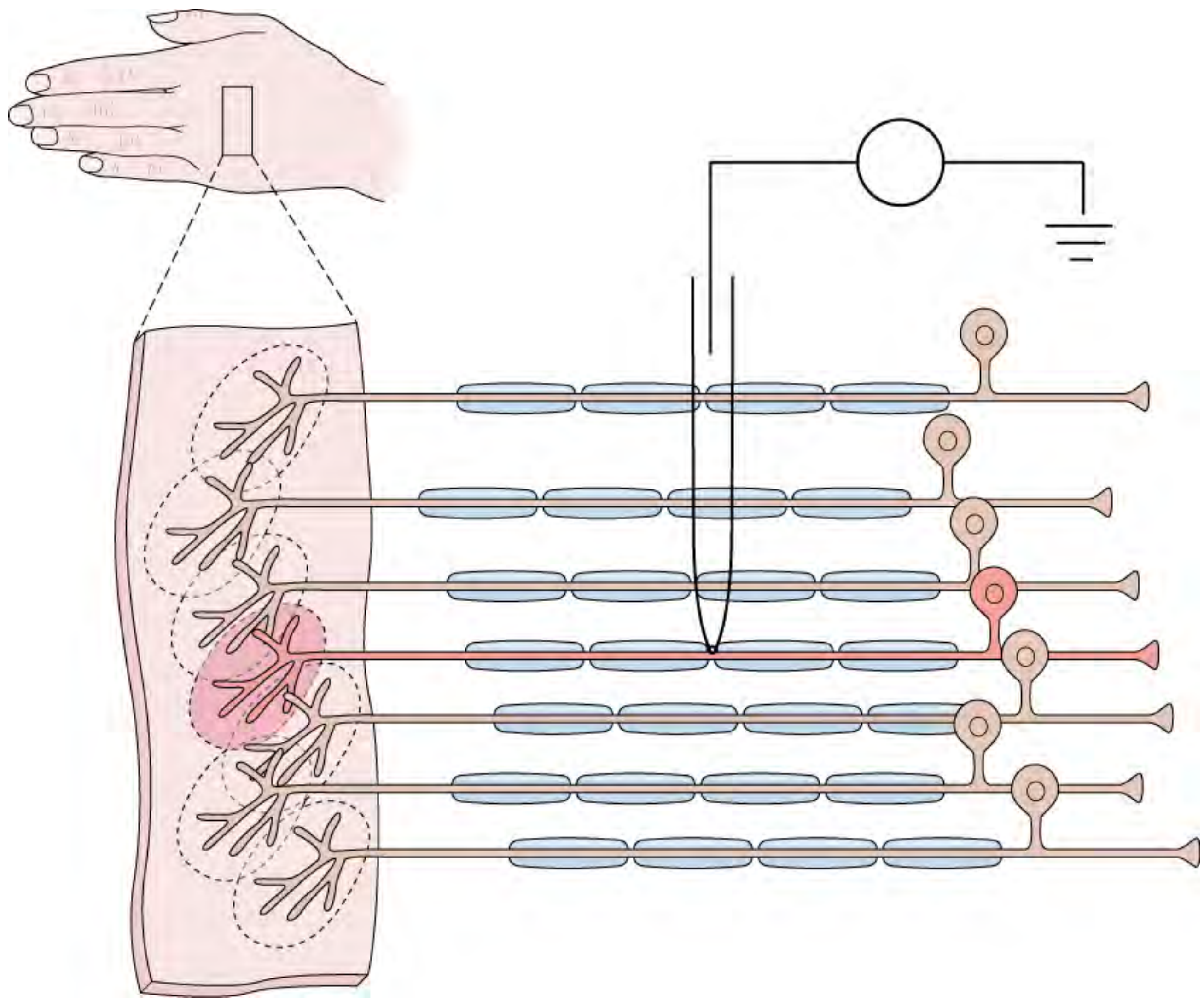


Johansson RS et al. *Brain Res* 1980

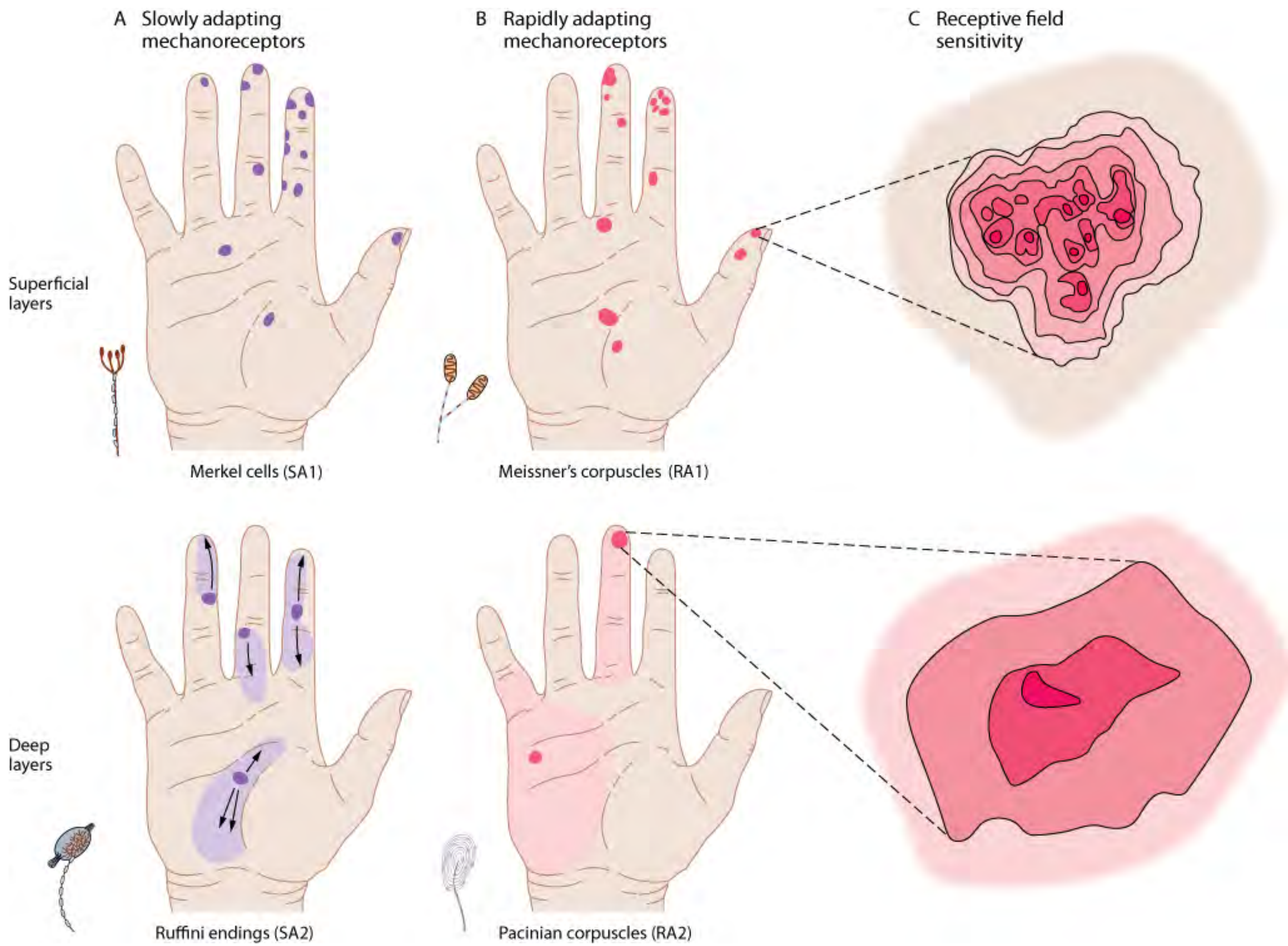
Receptive fields determine spatial properties

- The *receptive field* of a sensory neuron defines the spatial location where it responds to stimuli of the appropriate energy
- Spatial position of a receptor within the sense organ localizes the stimulus in space
- Where we are touched is coded by which specific touch fibers are activated

Nerve branch patterns define receptive fields



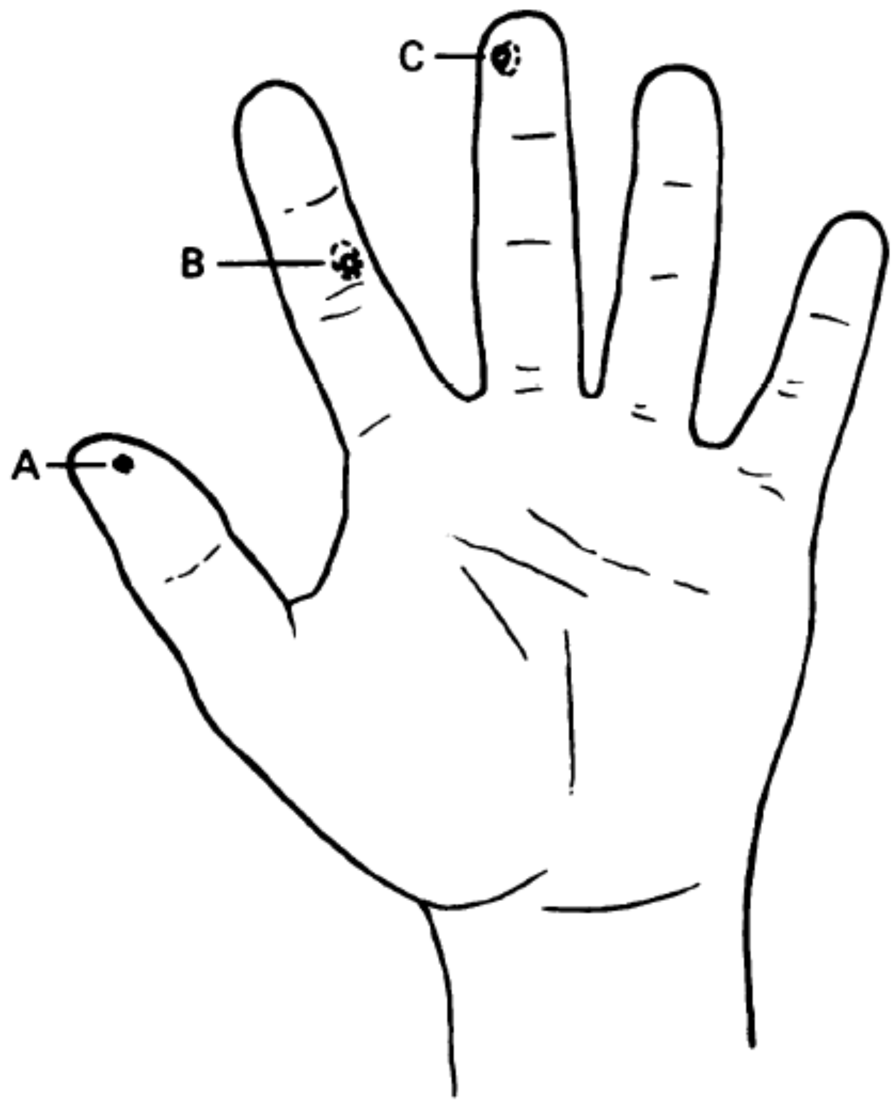
Receptive fields of touch receptors differ in size



Johansson RS, Vallbo ÅB. *Trends Neurosci* 1983

Receptive and perceptive fields coincide

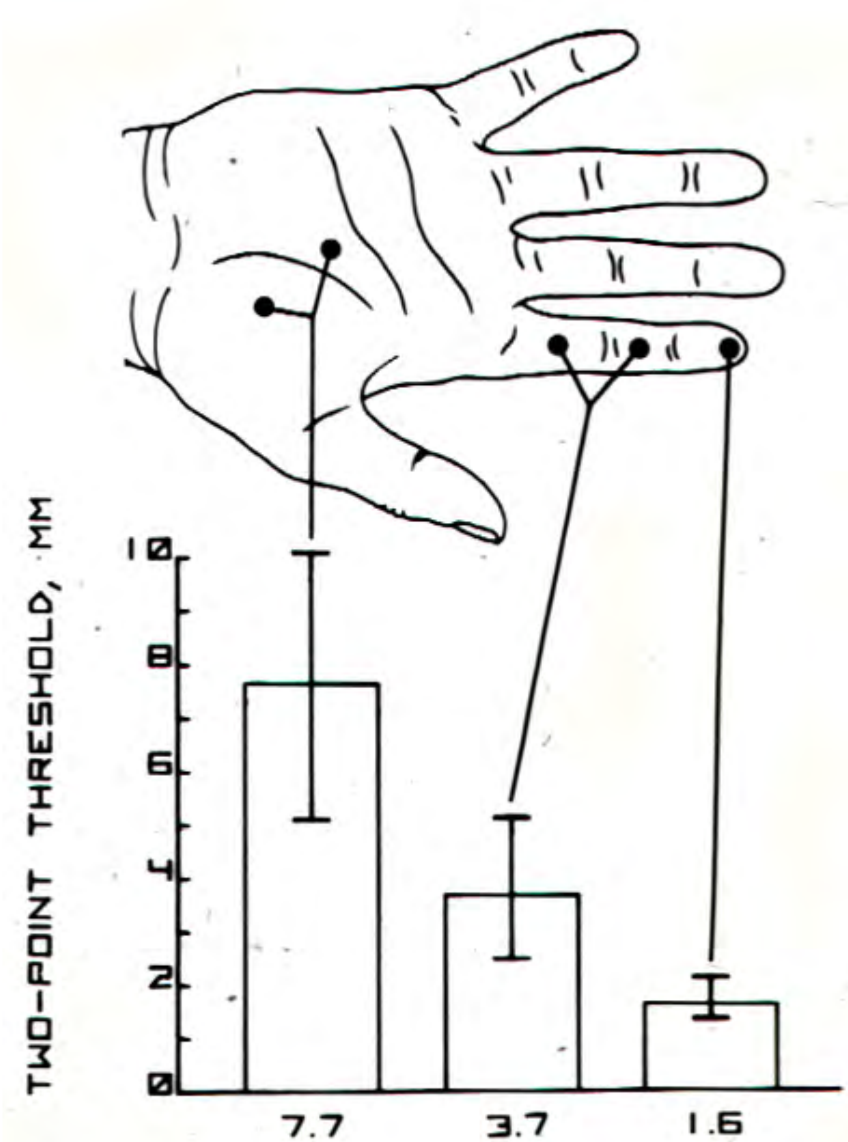
A = RA1 fiber:
(Tap or vibration)



B, C = SA1 fiber:
(Pressure)

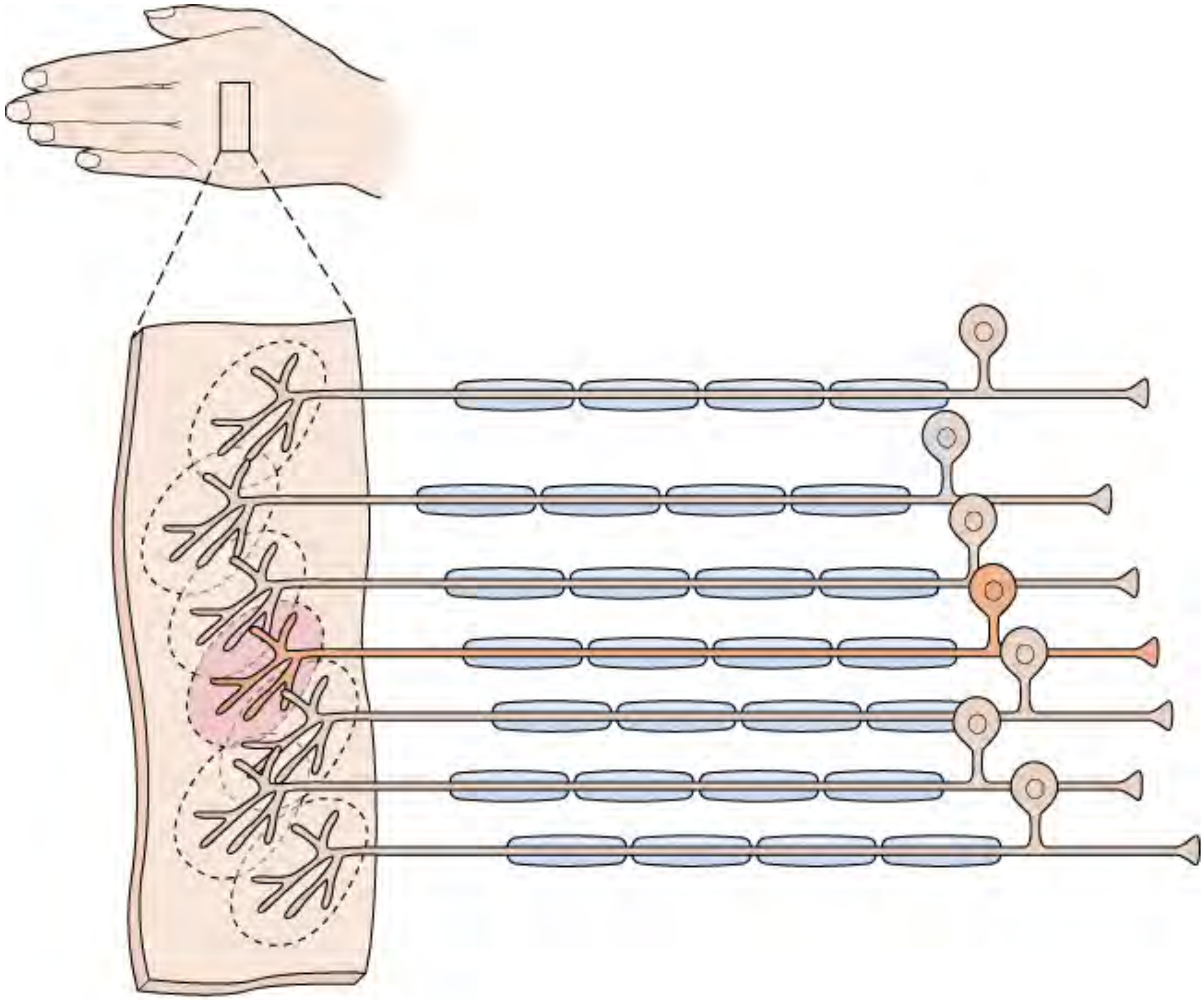
Torebjörk HE, et al. *Brain* 1987

Two-point thresholds are smallest on the hand

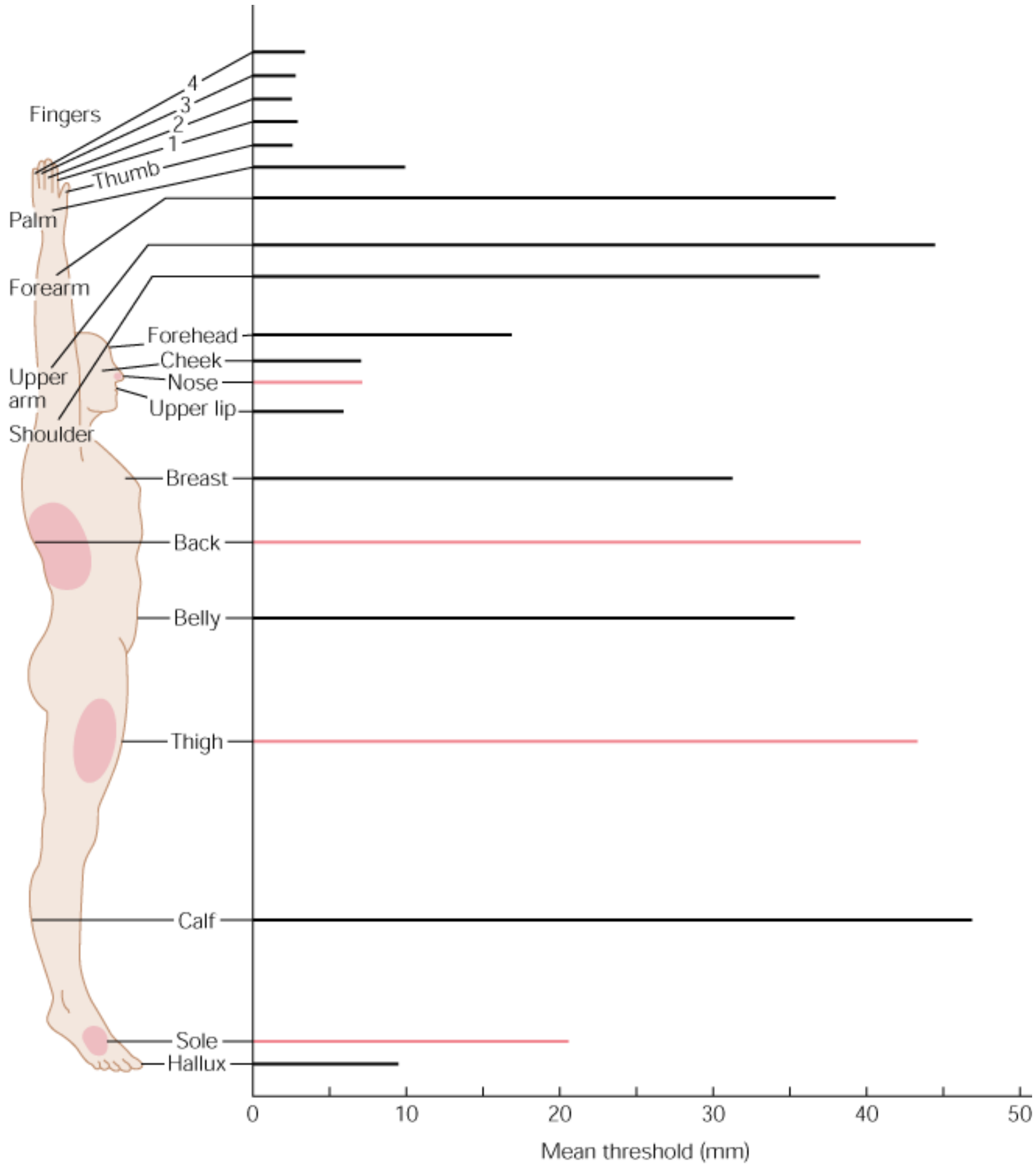


Vallbo ÅB, Johansson RS. 1978

Receptive field size determines spatial resolution

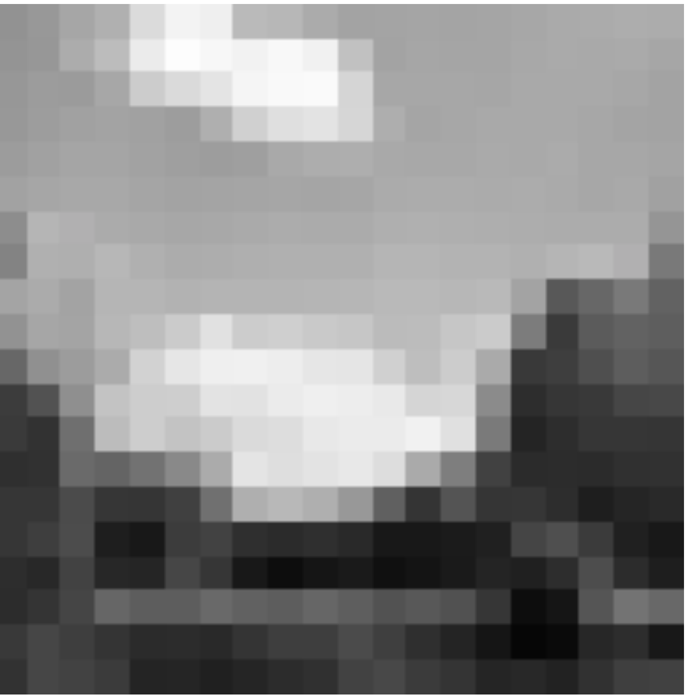


Two-point thresholds correlate with receptive field size



Weinstein S. *The Skin Senses* 1968

Spatial Resolution … and Receptive Fields



20 x 20 pixel

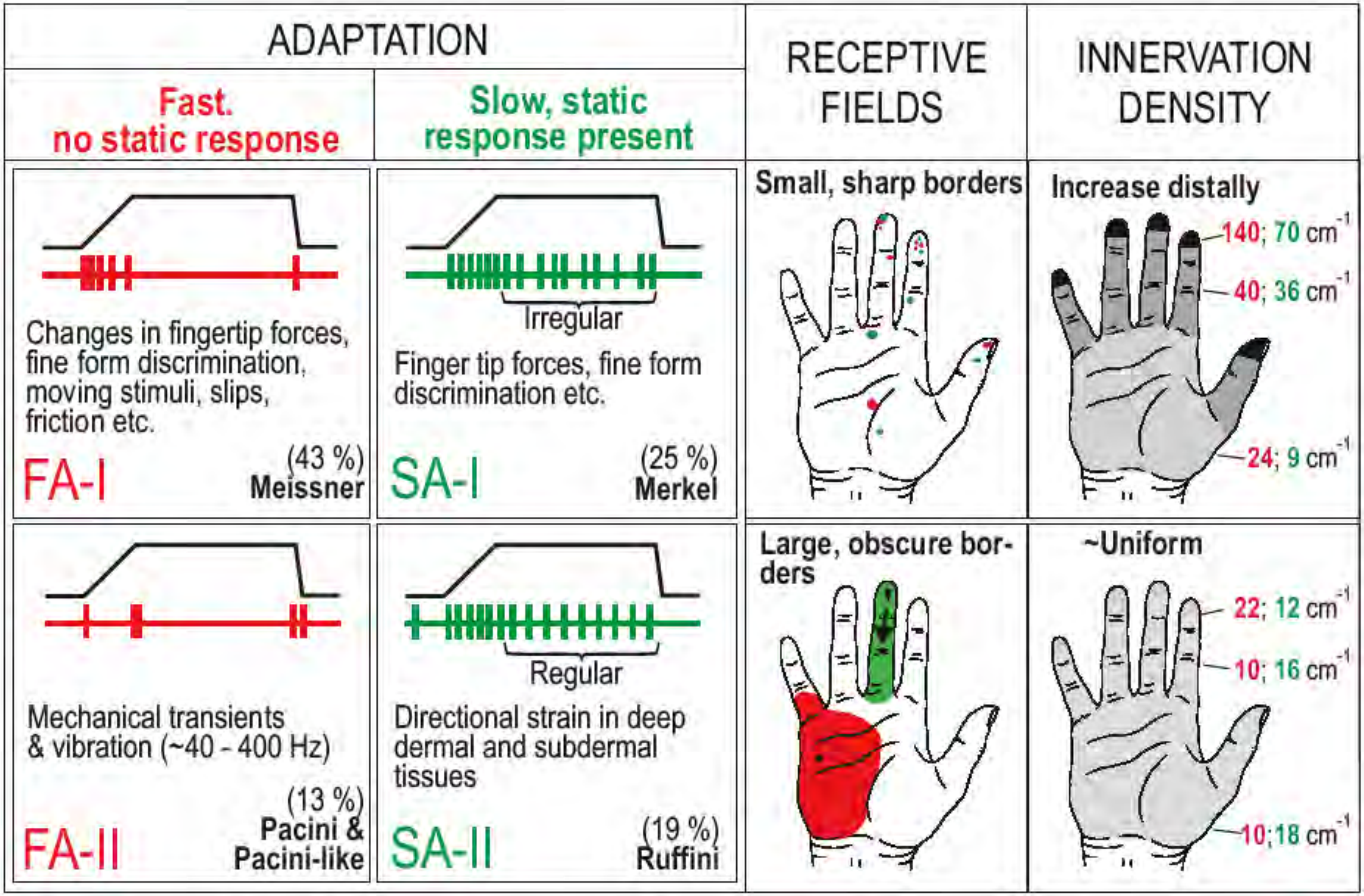
60 x 60 pixel

400 x 400 pixel

Two-point discrimination threshold

- Reflects receptive field diameters of Meissner’s corpuscle (RA1) and Merkel cell (SA1) afferents
- Receptive field diameter correlates inversely with innervation density
- Spatial acuity highest on densely innervated body regions (fingertips, lips, toes) that are used to touch external objects

Touch receptor response properties



Johansson RS, Flanagan JR. *Nature Rev Neurosci* 2009