ME 327: Design and Control of Haptic Systems
Spring 2020

Lecture 3: Human haptic perception

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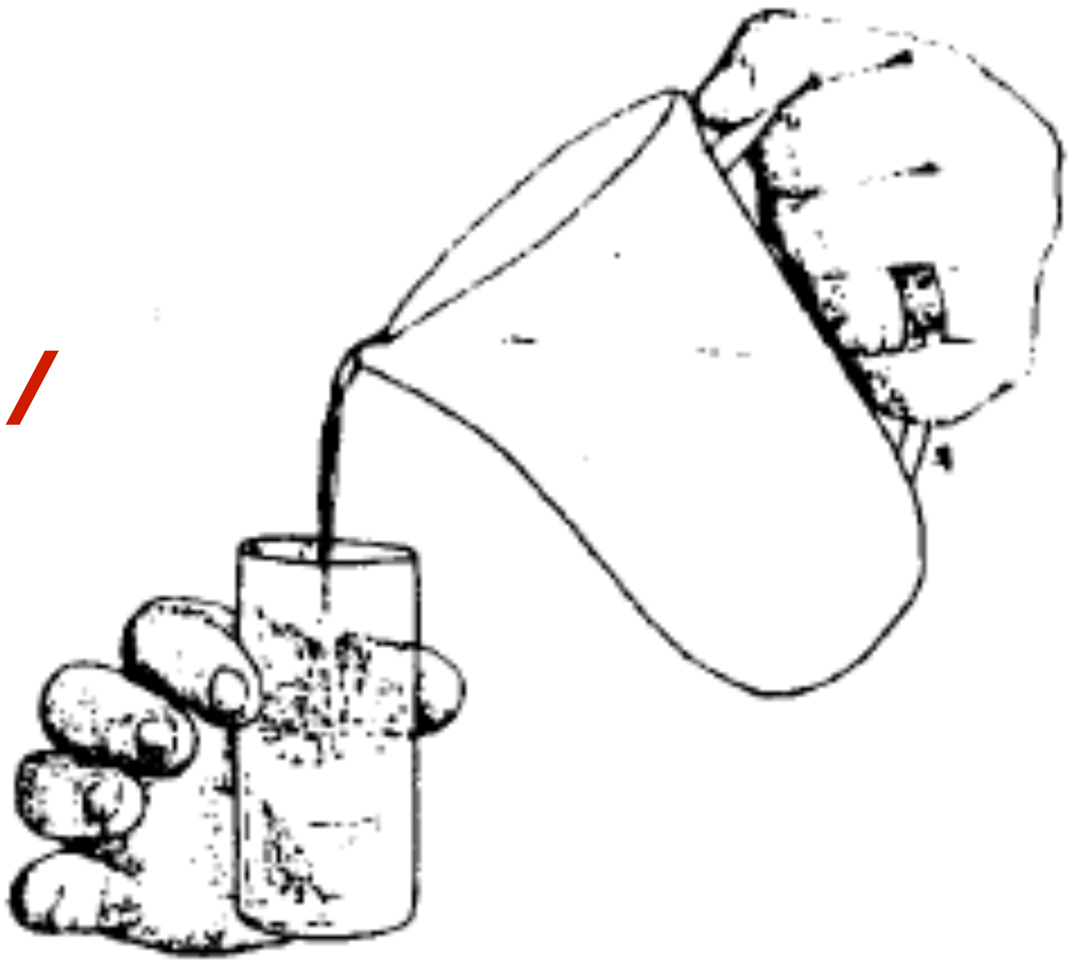
types of haptic sensing

cutaneous/ tactile

Related to the skin.



Johansson and Westling

kinesthesia/ proprioception/ force

A sense mediated by end organs located in muscles, tendons, and joints. Stimulated by bodily movements.

types of haptic sensing

tactile

spatial form	(SA I)
texture	(SA I, PC)
movement	(RA)
flutter	(RA)
vibration	(PC)

muscle force

(Golgi tendon organs)

body position/movement

(SA II, joint afferents, muscle spindles)

stereognosis

(SA I, Proprioceptors)

pain

pricking pain (A δ)

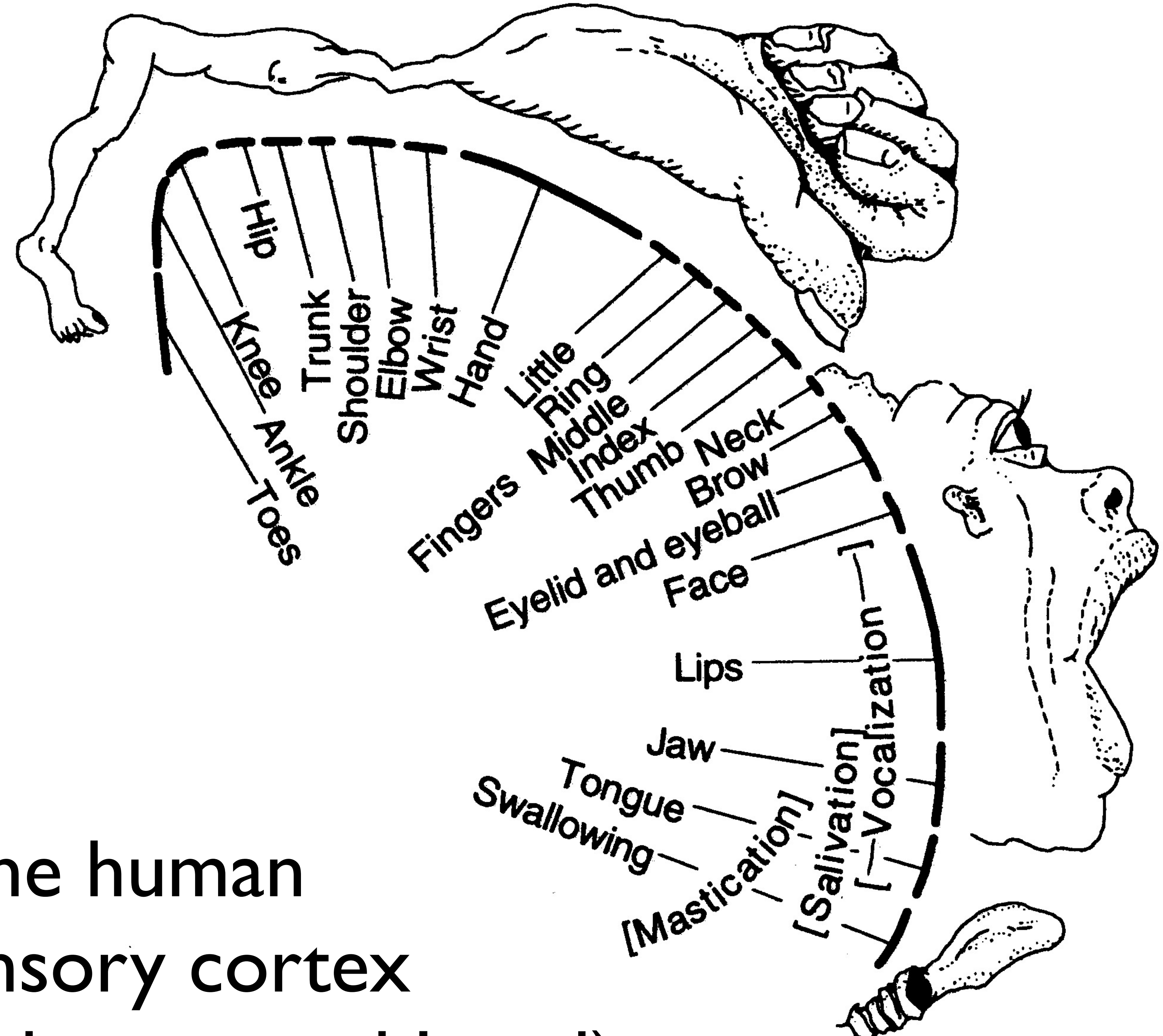
burning pain (C fiber)

temperature

cold (A δ)

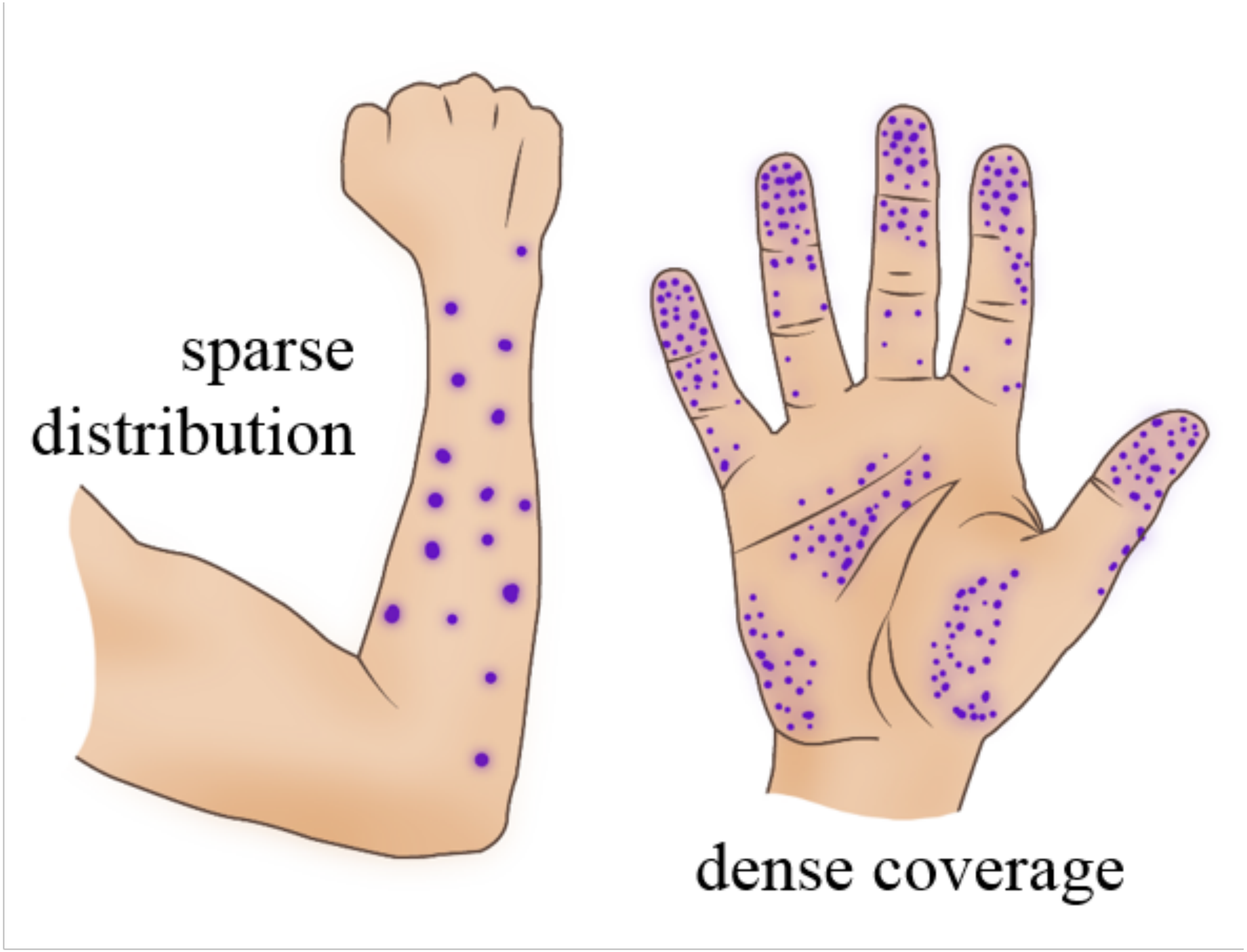
warm (C fiber)

sensory homunculus



mapping the human somatosensory cortex (Kandel, Schwartz and Jessel)

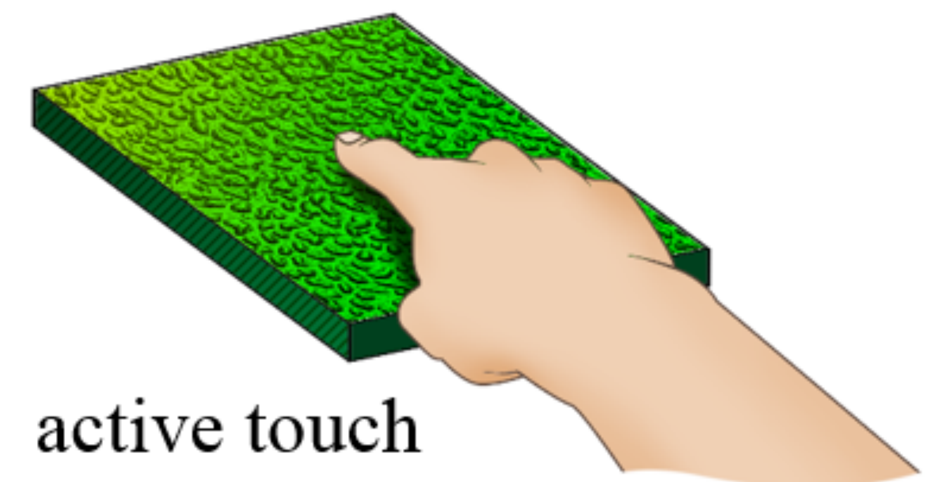
arms vs. fingertips

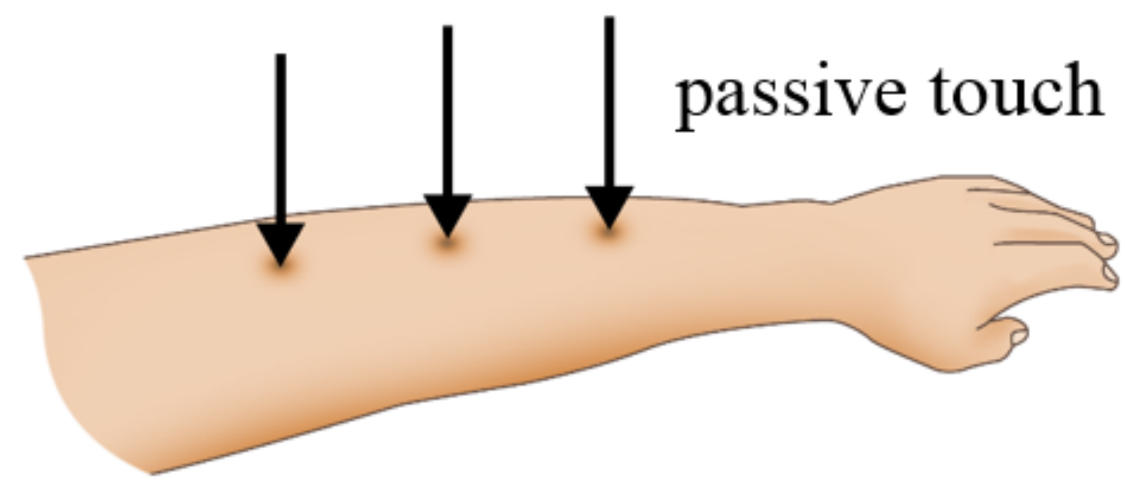


Images courtesy Even Pezent

active vs. passive touch

- Active touch
  - Focus on the object
- Passive touch
  - Focus on the sensation experienced
- How is this important to haptic device design?





Images courtesy Even Pezent

mechanoreception

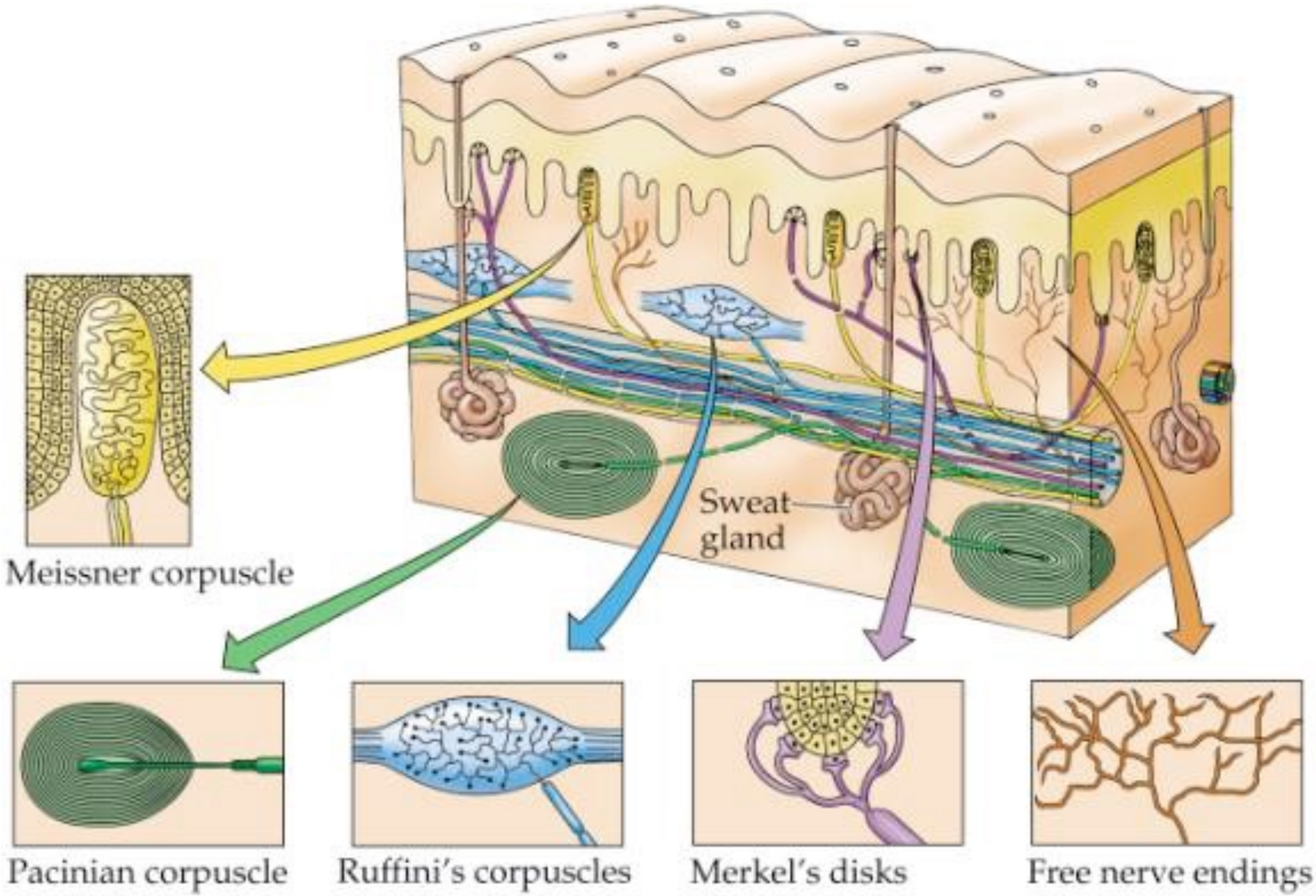
mechanoreceptive afferents

classified by depth:
I: closer to skin surface
II: deeper beneath surface

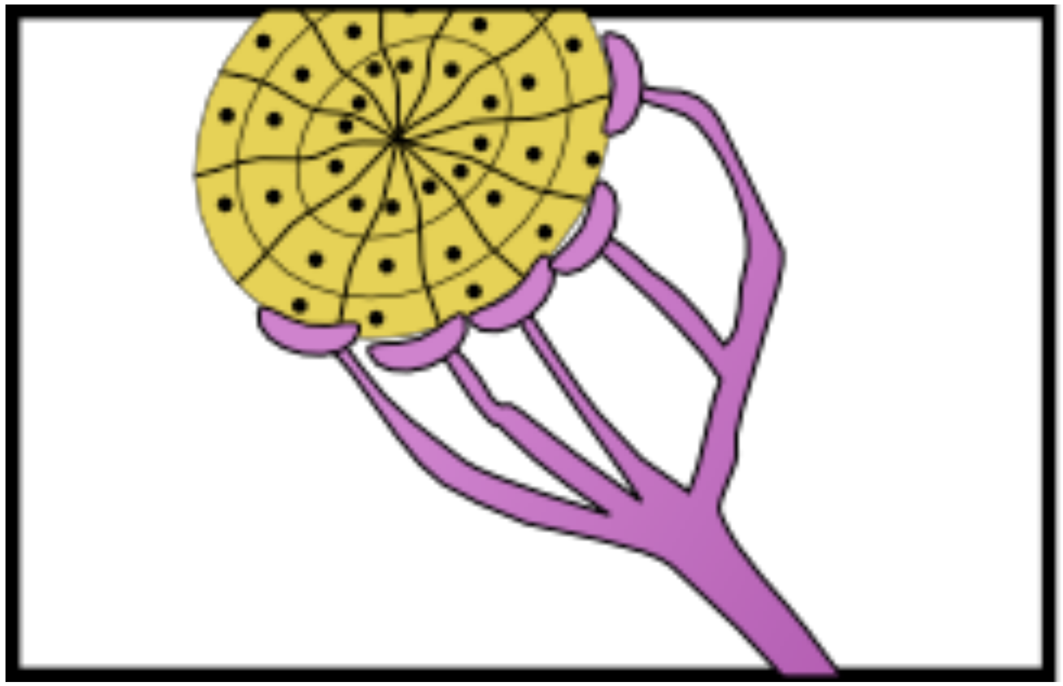
classified by rate of adaptation:
rapidly adapting = phasic
slowly adapting = tonic

classified by sensing modality:
e.g., receptor structure

cross section of glabrous skin



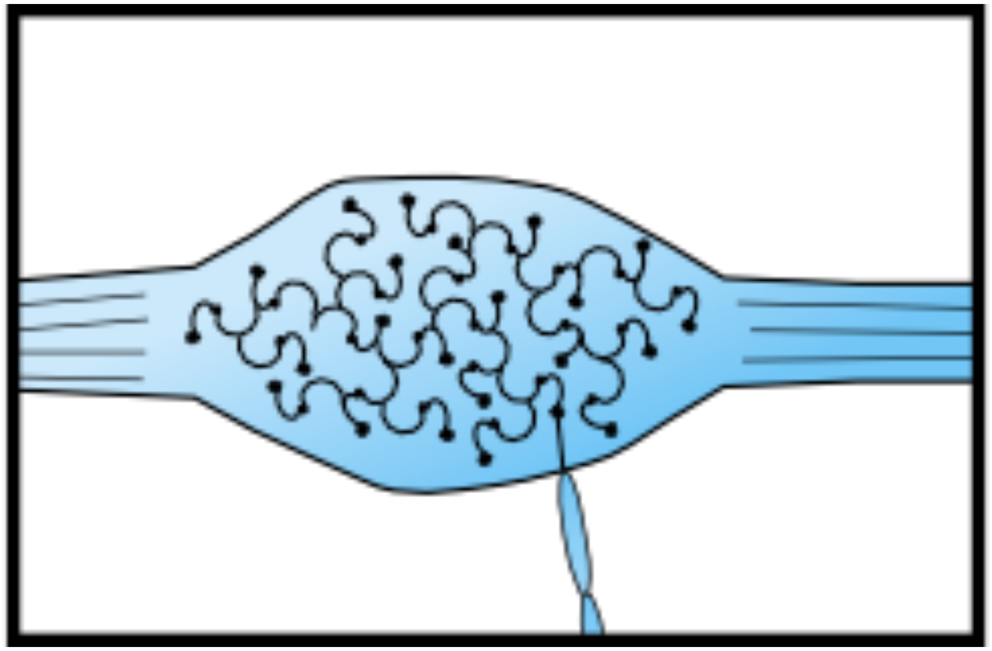
Merkel (SA 1)



- form and texture perception
- low-frequency vibrations

Shape: disk
Location: near border between epidermis & dermis
Type: SA I
Best Frequencies: 0.3-3 Hz
Stimulus: pressure

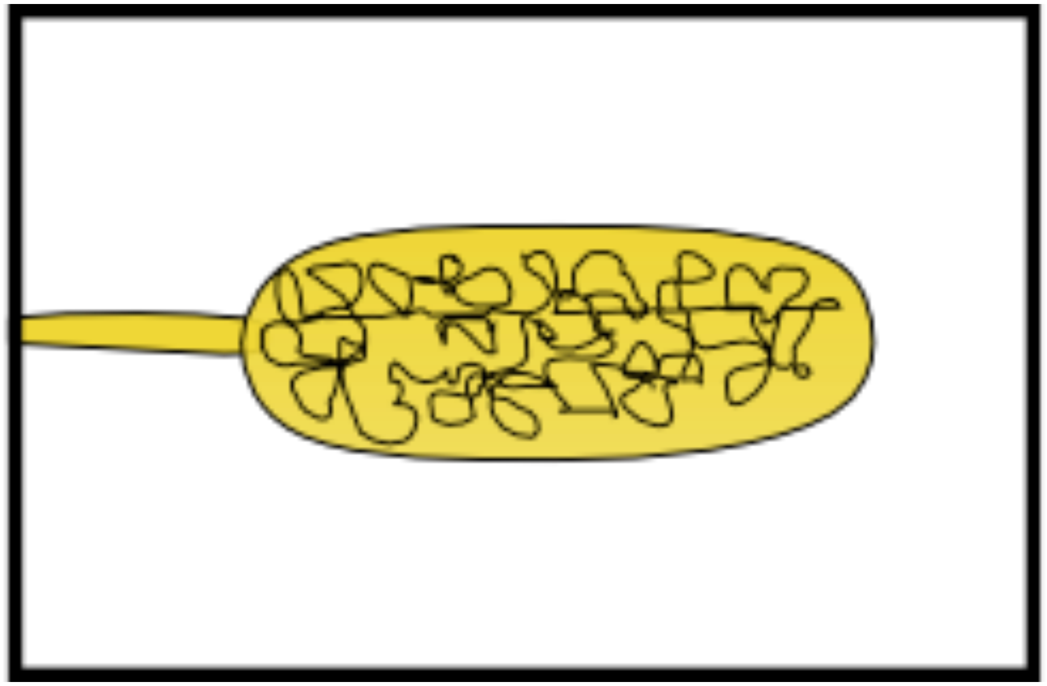
Ruffini (SA II)



- static and dynamic skin deformation
- skin stretch

Shape: many-branched fibers inside a roughly cylindrical capsule
Location: dermis
Type: SA II
Best Frequencies: 15-400 Hz
Stimulus: stretching of skin or movement of joints

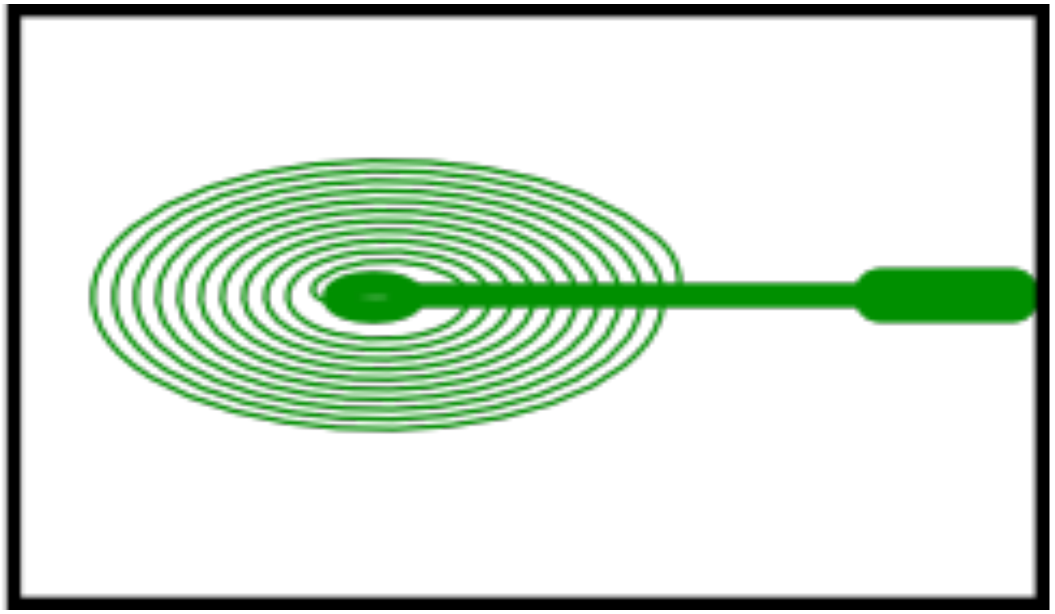
Meissner (RA I)



- motion, slip/grip
- dynamic skin deformation

Shape: stack of flattened cells, with a nerve fiber winding its way through
Location: in dermis just below epidermis
Type: RA I
Best Frequencies: 3-40 Hz
Stimulus: taps on skin

Pacinian Corpuscle (PC / RA II)



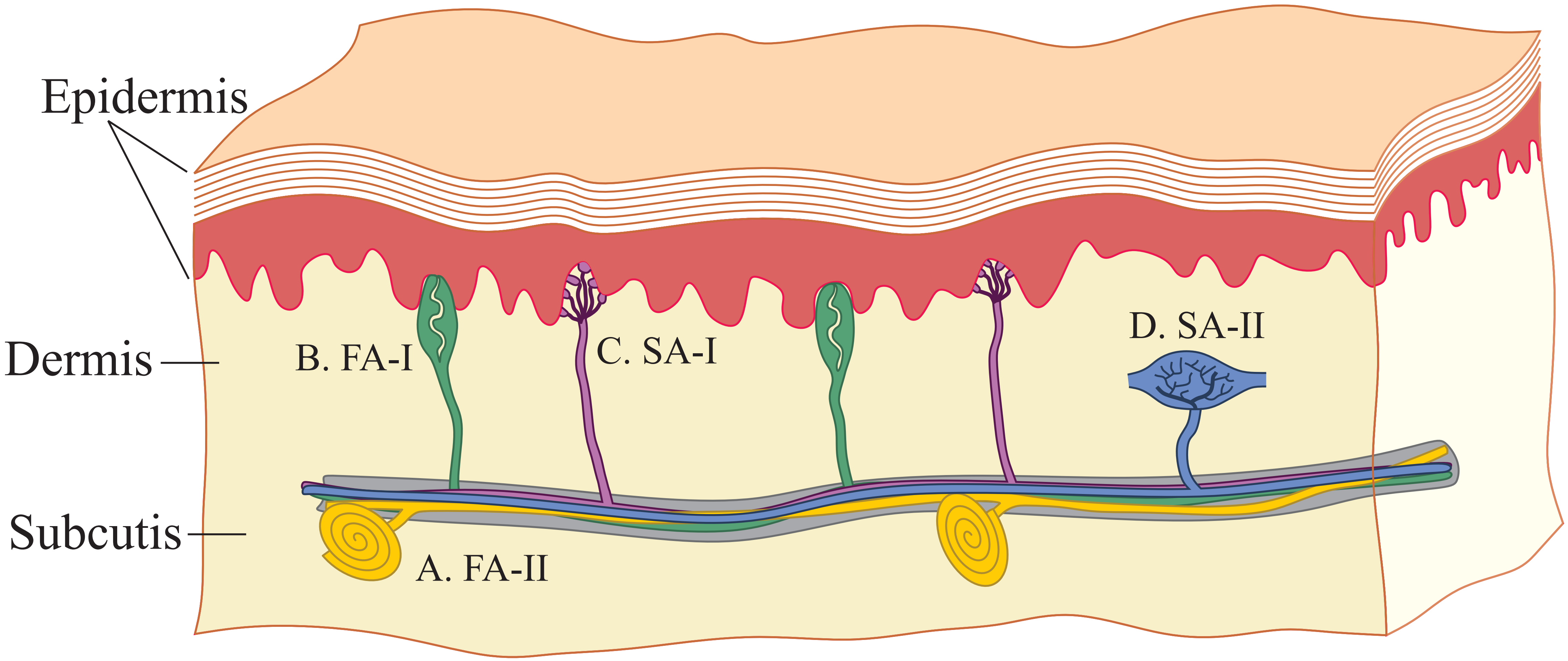
- high frequency vibration
- gross pressure changes

Shape: layered capsule surrounding nerve fiber
Location: deep in skin
Type: PC
Best Frequencies: 10 to >500 Hz
Stimulus: rapid vibration

cutaneous mechanoreceptors

	Receptor	Diam.	Density (Fibers/cm^2)	Response	Percep. Function
SA I	Merkel	2mm	100	curvature	form & texture
RA	Meissner	5 mm	150	motion	motion & grip control
SA II	Ruffini	8mm	20	stretch	hand shape, lateral force
PC	Pacinian	Hand	20	vibration	tools & probes

Summary of human mechanoreceptors



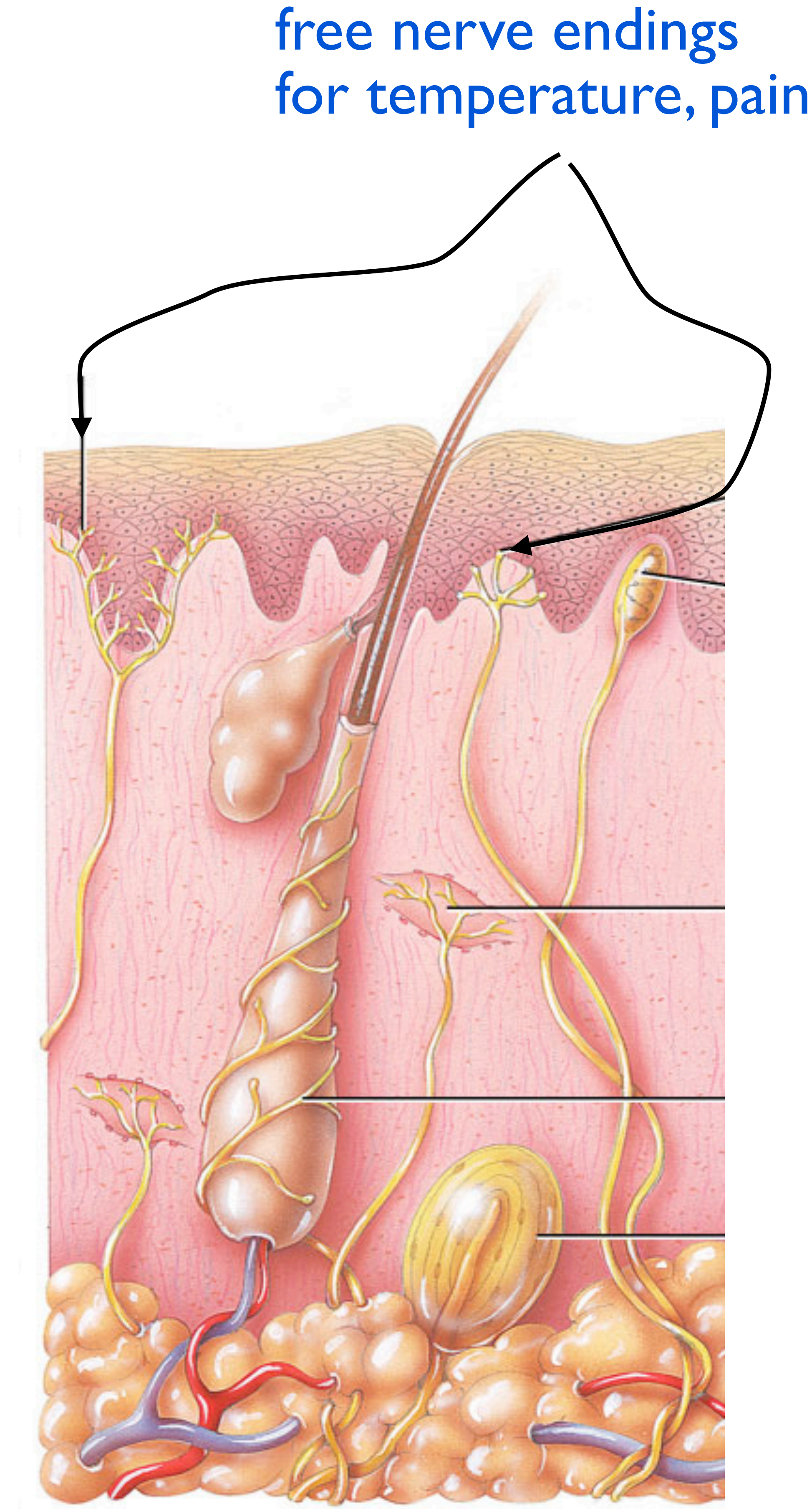
Cutkosky M.R. and Ulmen, J., "Dynamic tactile sensing," in The Human Hand as an Inspiration for Robotic Hands, Springer Verlag.

Receptor	receptive field	frequency range	sensed quantity
FA-I Meissner corpuscles 140/cm^2 on fingertips	3-4mm	5-60 Hz	dynamic skin deformation
SA-I Merkel endings 70/cm^2	3-4mm	0-5 Hz	compressive stresses
FA-II Pacini corpuscles	>20mm	50-500+ Hz (peak sensitivity ~250 Hz)	vibration
SA-II Ruffini endings	>10mm	0-10 Hz	directional skin stretch

table data from various sources (see Johansson & Flanagan 2009 for a review)

Thermal sensing

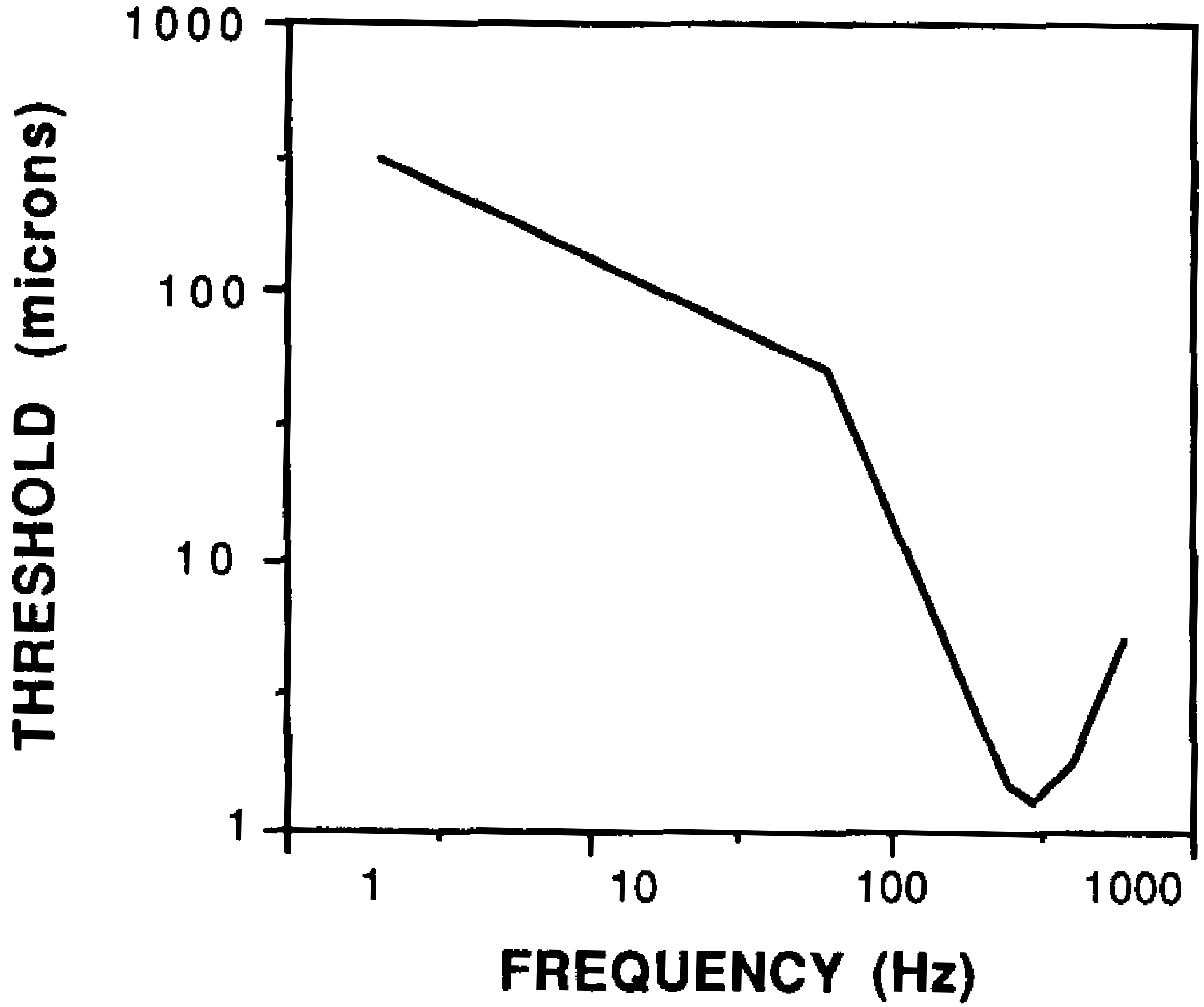
- separate warm and cold receptors whose firing rate depends on magnitude of difference w.r.t body temperature
- both slowly adapting (SA) and rapidly adapting (FA) characteristics, so depends on both T and dT/dt
- perception strongly affected by body temperature versus temperature at surface of skin (aluminum feels cooler at room temperature than wood) -- an important component of material identification



R.K. Adair. A model of the detection of warmth and cold by cutaneous sensors through effects on voltage-gated membrane channels, ***PNAS*** 1999 96 (21).

Slide courtesy Mark Cutkosky

Pacinian corpuscle (FA-II) sensitivity to vibrations and Meissner (FA-I) sensitivity to small features



Peak sensitivity around 300 Hz.

Able to detect bumps of a few microns under ideal conditions

Adapted from data in Verrillo, R.T., Vibrotactile thresholds measured at the finger, *Perception & Psychophysics*, Vol. 9 (4) (1971).

Slide courtesy Mark Cutkosky

kinesthesia

kinesthetic sensing

perception of limb movement & position, **force**

- muscle receptors (muscle spindles and Golgi tendon organs)
- joint receptors (in capsules and ligaments of joints)
- skin receptors (slowly adapting cutaneous mechanoreceptors that measure skin stretch): Ruffini endings, Merkel Cells in hairy skin

force sensing

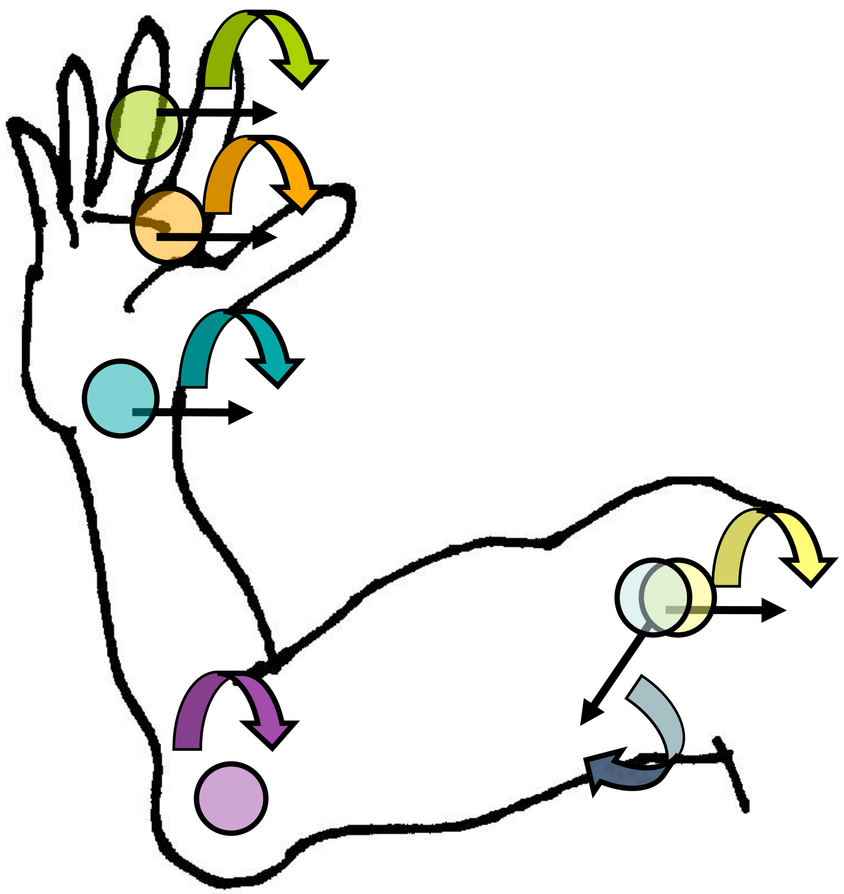
- Resolution 0.06 N
- Grasping force: 400 N!

- Get comfortable with the feeling of Newton, since haptic renderings will be displayed in SI units. (E.g., a stiffness of 100 N/m)

proprioception

- derived from Latin, *proprius*, meaning "belonging to one's own self"
- in general, it provides a sense of static position and movement of the limbs and body in relation to one other and the world
- in much of the literature, proprioception is defined as the perception of positions and movements of the body segments in relation to each other (without aid of vision, touch, or the organs of equilibrium). This is in contrast to **exteroception**.

Just Noticeable Differences at Joints



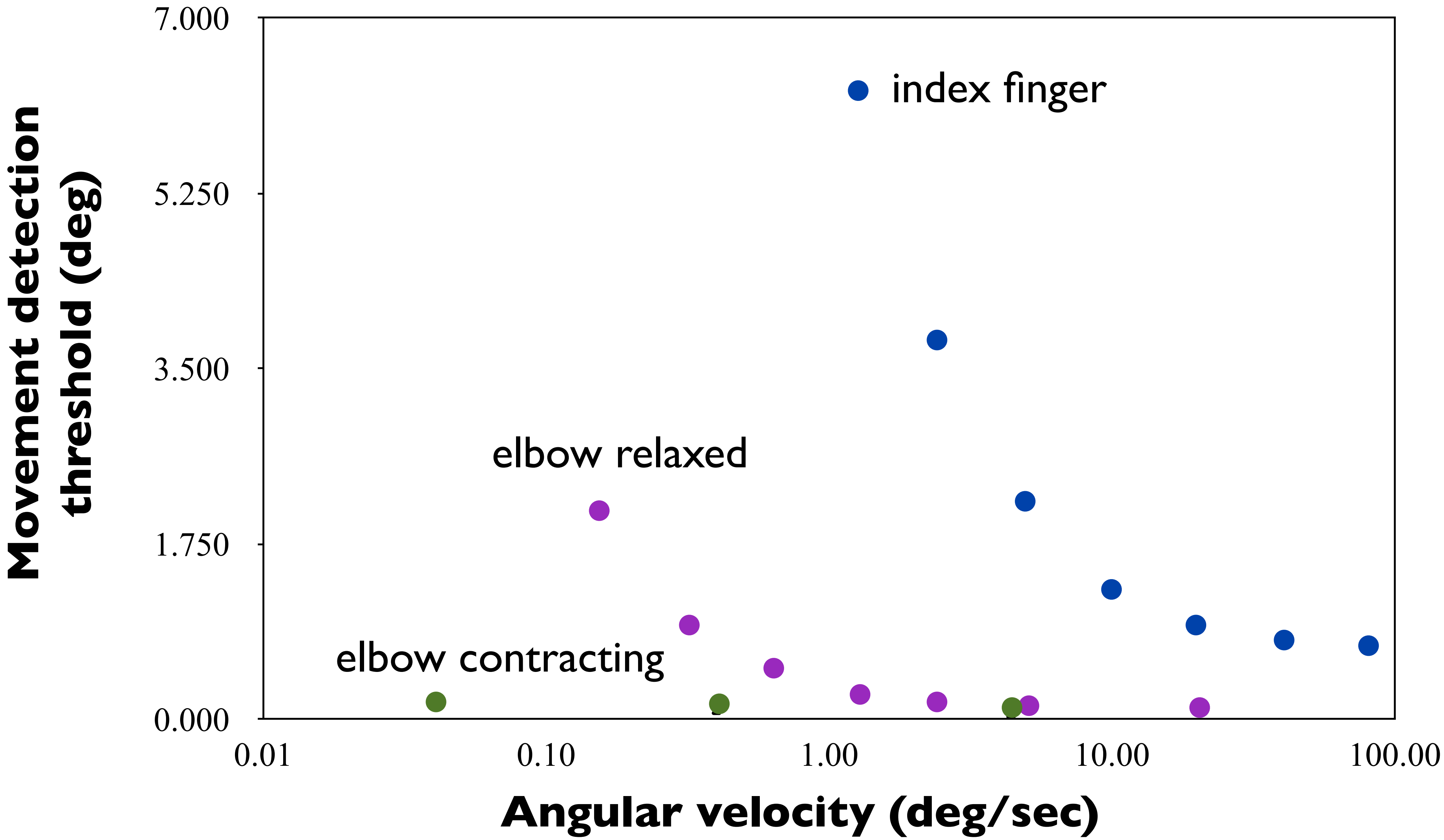
	Proximal-InterPhalangeal (PIP) Joint	~2.5°/*6.8°
	MetaCarpalPhalangeal (MCP) Joint	~2.5°/*4.4°
	Wrist	2.0°
	Elbow	2.0°
	Shoulder (front)	0.8°
	Shoulder (side)	0.8°

H. Z. Tan, M. A. Srinivasan, B. Eberman, and B. Cheng, "Human factors for the design of force-reflecting haptic interfaces." In Proc. of 3rd Int. Symp. Haptic Interfaces for Virtual Environment and Teleoperator Systems, ASME Dynamic Systems and Control Division, 55(1):353-359, 1994.

L. A. Jones, "Kinesthetic Sensing", unpublished, 2000.

movement and position

threshold can depend on velocity and whether muscle is contracted



Jones, 2000