The somatosensory system

(aka, why you feel touch and
can locate your body: the 6th sense…)

Prof. Mackenzie Mathis

Image credit:
https://www.mallgalleries.org.uk/

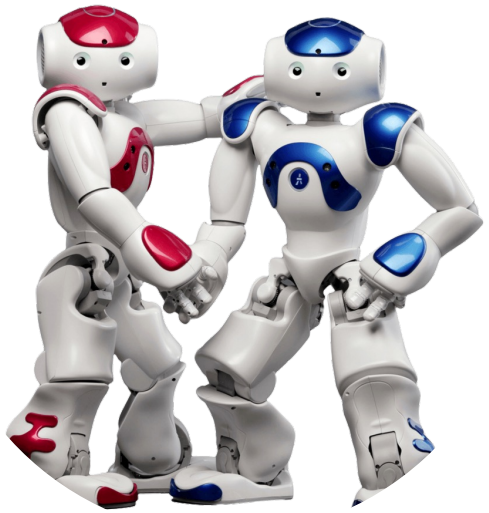
Welcome!

Today's topics:

- Somatosensory system
  - (anatomy) and function
- Proprioception
- Touch

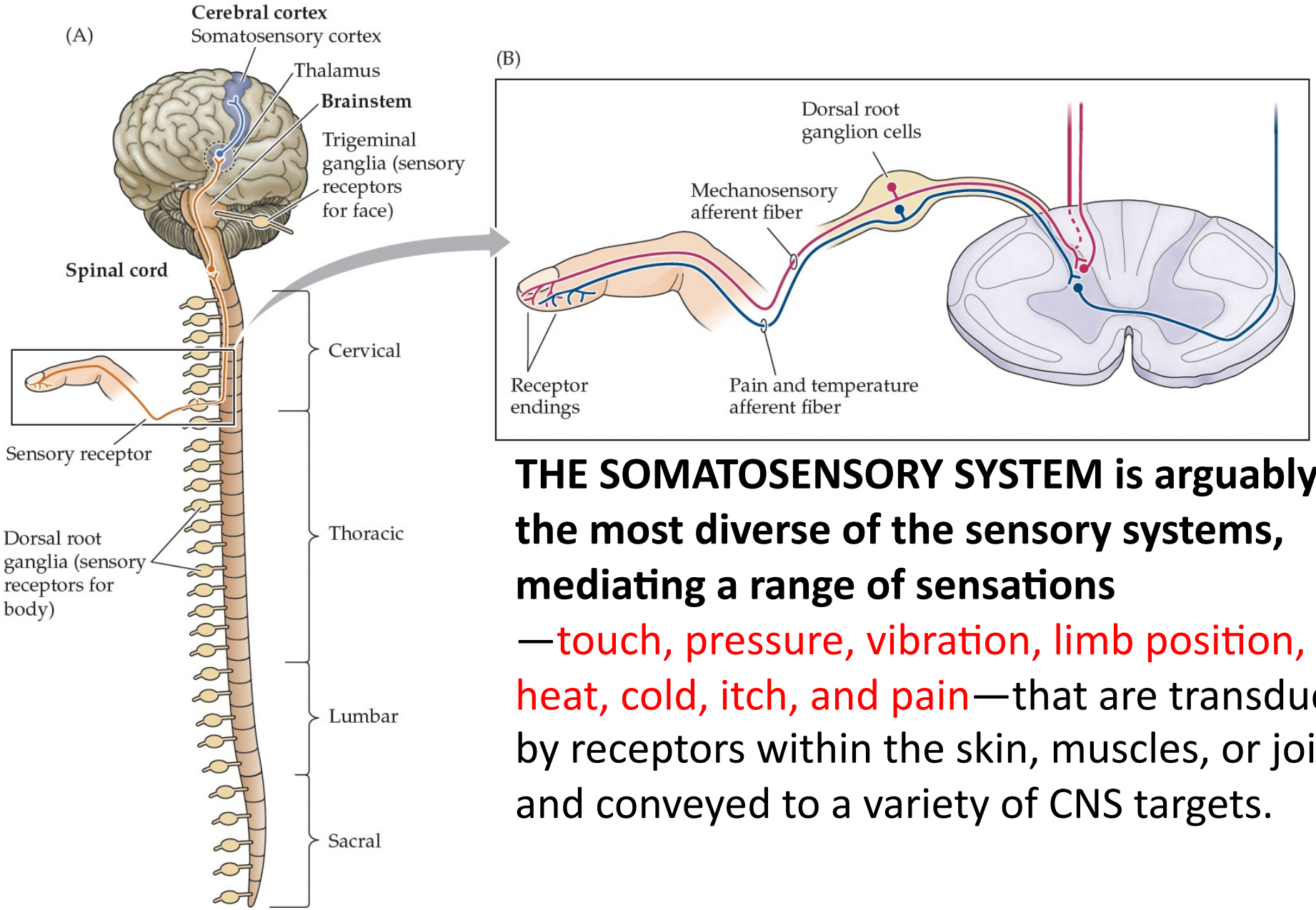
Reading Material:

- Chapter 9



Videos of interest:
https://www.youtube.com/watch?v=kUsSU_MVYd8
https://www.youtube.com/watch?v=2ENakkiIZc0
https://www.youtube.com/watch?v=2ENakkiIZc0

What is the somatosensory system?



THE SOMATOSENSORY SYSTEM is arguably the most diverse of the sensory systems, mediating a range of sensations

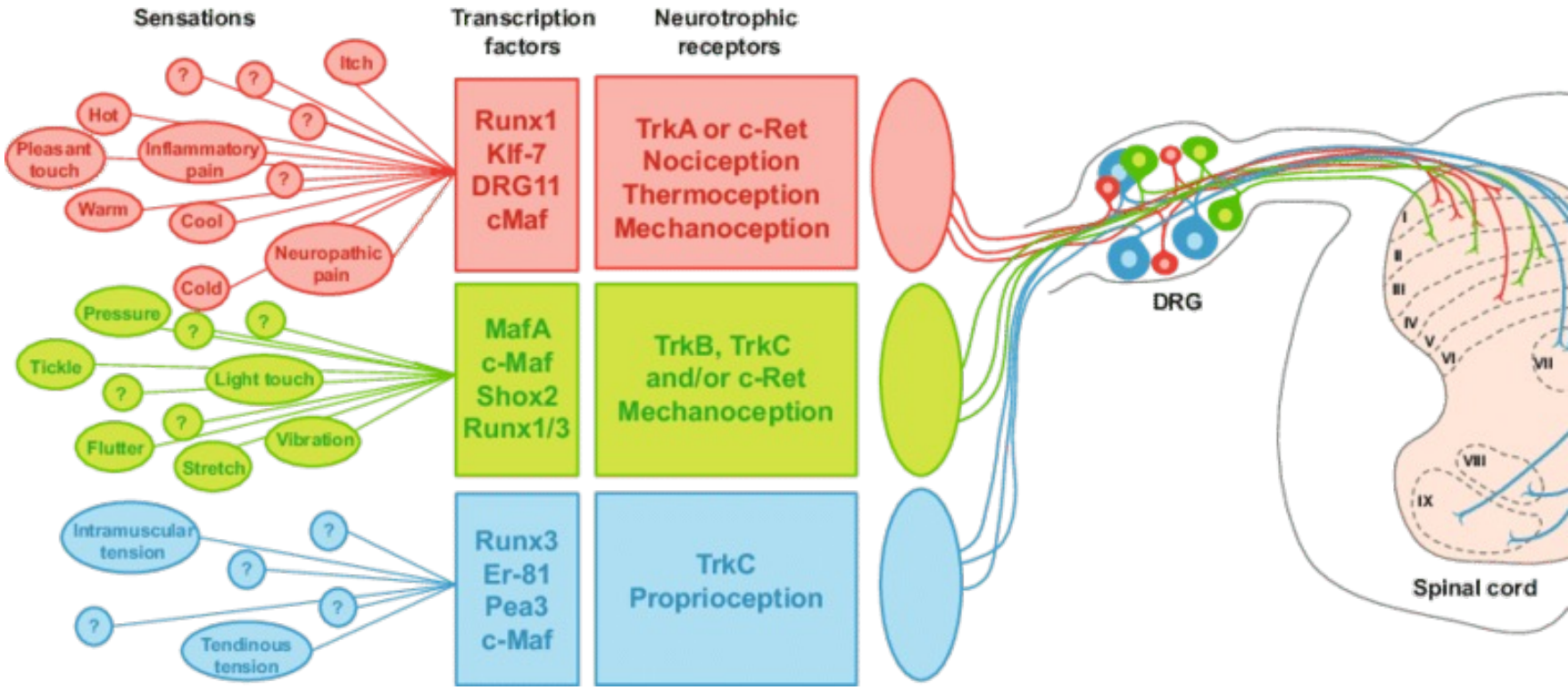
—touch, pressure, vibration, limb position, heat, cold, itch, and pain—that are transduced by receptors within the skin, muscles, or joints and conveyed to a variety of CNS targets.

sensory transduction—the process of converting the energy of a stimulus into an electrical signal—is similar in all somatosensory afferents!

How it works:

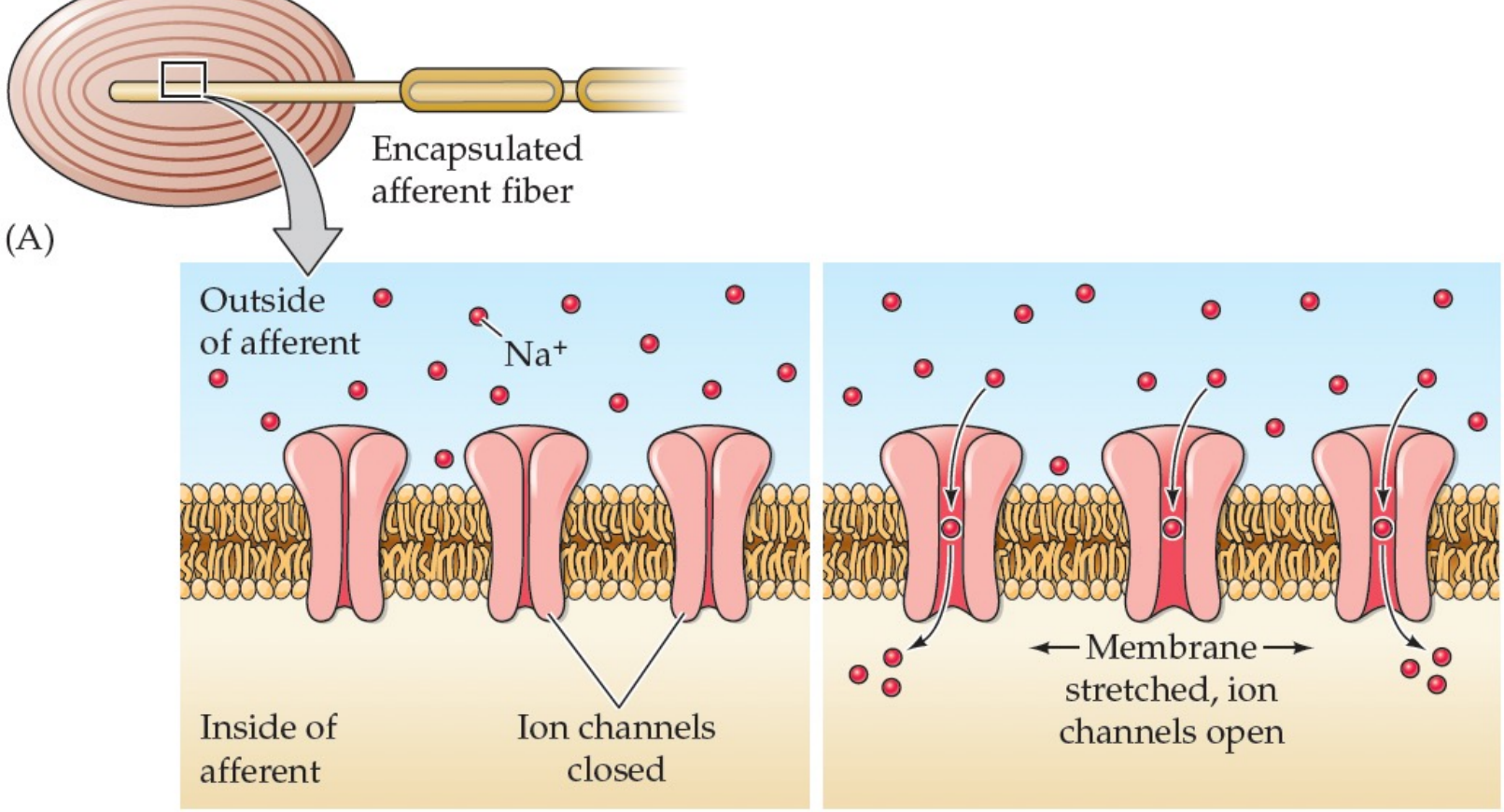
A stimulus alters the permeability of cation channels in the afferent nerve endings, generating a depolarizing current known as a **receptor potential.**

Somatosensory afferents differ significantly in their response properties. These differences, taken together, define distinct classes of afferents, each of which makes unique contributions to somatic sensation.



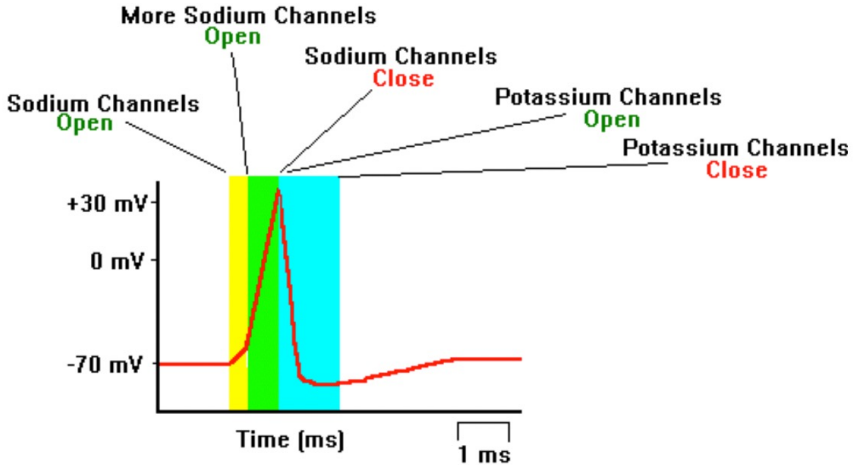
[Neurotrophin Signalling and Transcription Programmes Interactions in the Development of Somatosensory Neurons]

sensory transduction:
Mechanoreceptors!

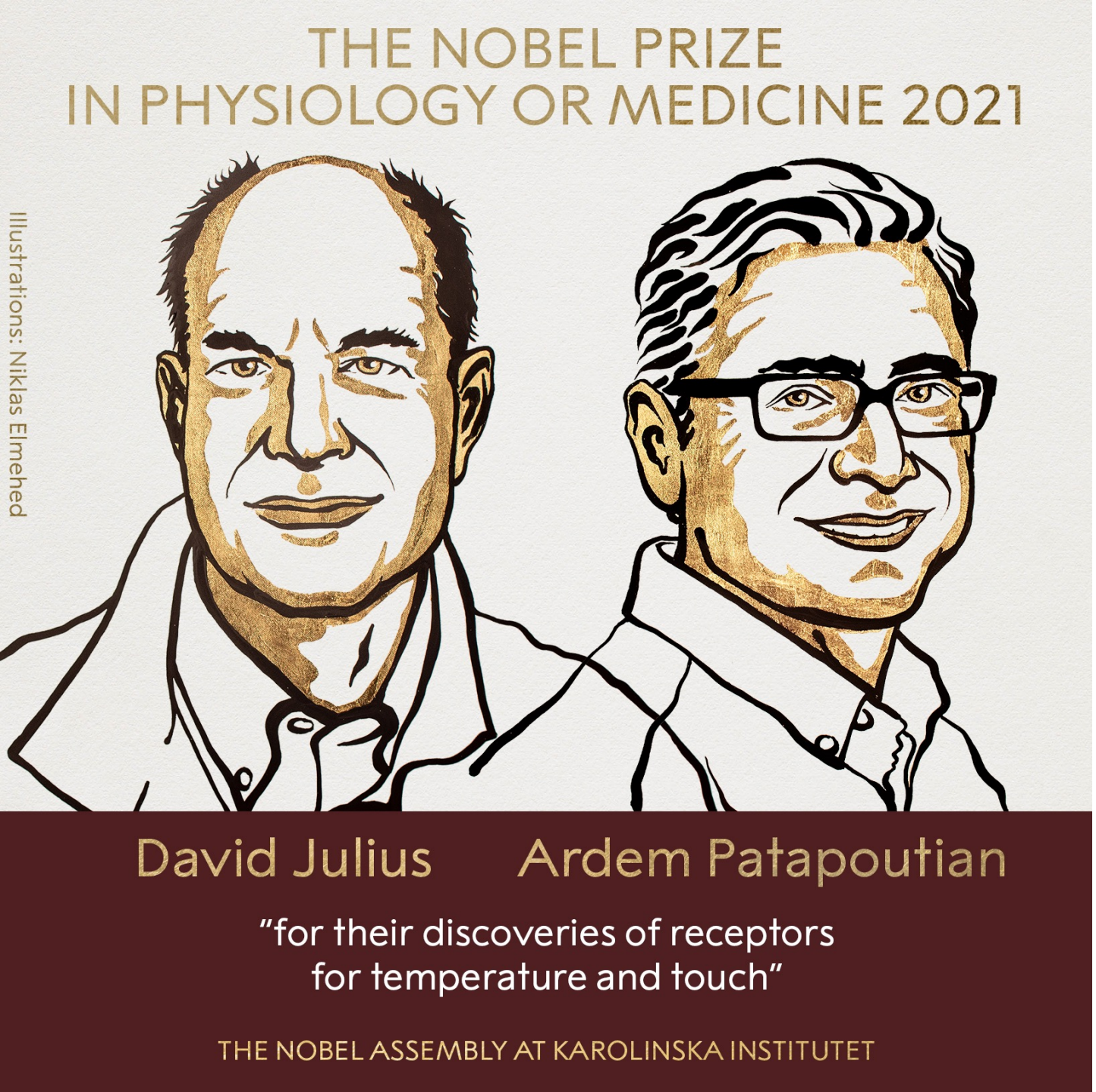


Reminder:

Na+/K+ channels:



2 relevant ion channels:
1) Mechanosensitive ion channel (create "graded response")
2) Voltage-gated Na^+ channel (not shown):
make the action potential (AP), called here "spike potential"



David Julius used capsaicin, the compound in chili pepper that elicits the sensation of heat, to identify the gene encoding the first temperature sensor, the ion channel **TRPV1**.

Ardem Patapoutian discovered a family of pressure-sensitive ion channels, the **Piezos** that are highly conserved throughout the animal kingdom.

Breaking it down: types of receptors are linked to sensory function!

TABLE 9.1 ■ Somatosensory Afferents That Link Receptors to the Central Nervous System

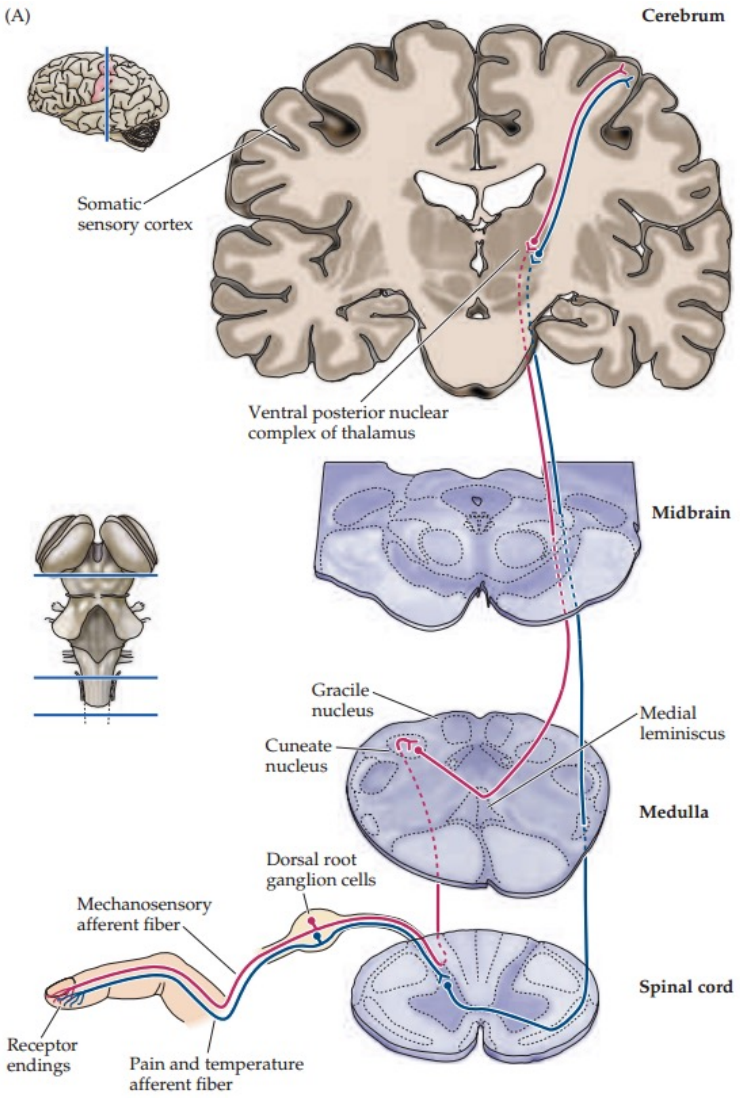
Sensory function	Receptor type	Afferent axon type[a]	Axon diameter	Conduction velocity
Proprioception	Muscle spindle	Ia, II	13–20 μm	80–120 m/s
Touch	Merkel, Meissner, Pacinian, and Ruffini cells	Aβ	6–12 μm	35–75 m/s
Pain, temperature	Free nerve endings	Aδ	1–5 μm	5–30 m/s
Pain, temperature, itch, non-discriminative touch	Free nerve endings (unmyelinated)	C	0.2–1.5 μm	0.5–2 m/s

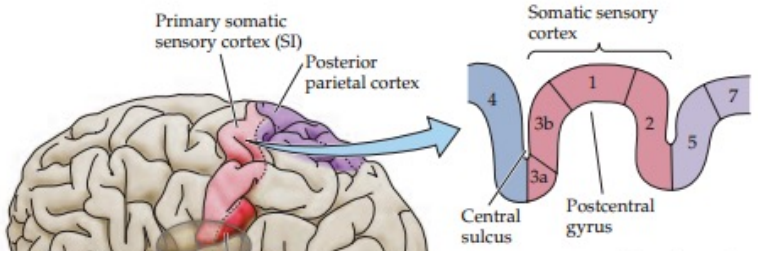
Axon diameter is one factor that differentiates classes of somatosensory afferents:

- The largest-diameter sensory afferents (designated Ia) are those that supply the sensory receptors in the muscles.
- Most of the information subserving touch is conveyed by slightly smaller diameter fibers (Aβ afferents)
- Information about pain and temperature is conveyed by even smaller diameter fibers (Aδ and C).

Into the brain: overview of the anatomy of feedback

afferent fiber: Information is carried from periphery to the CNS

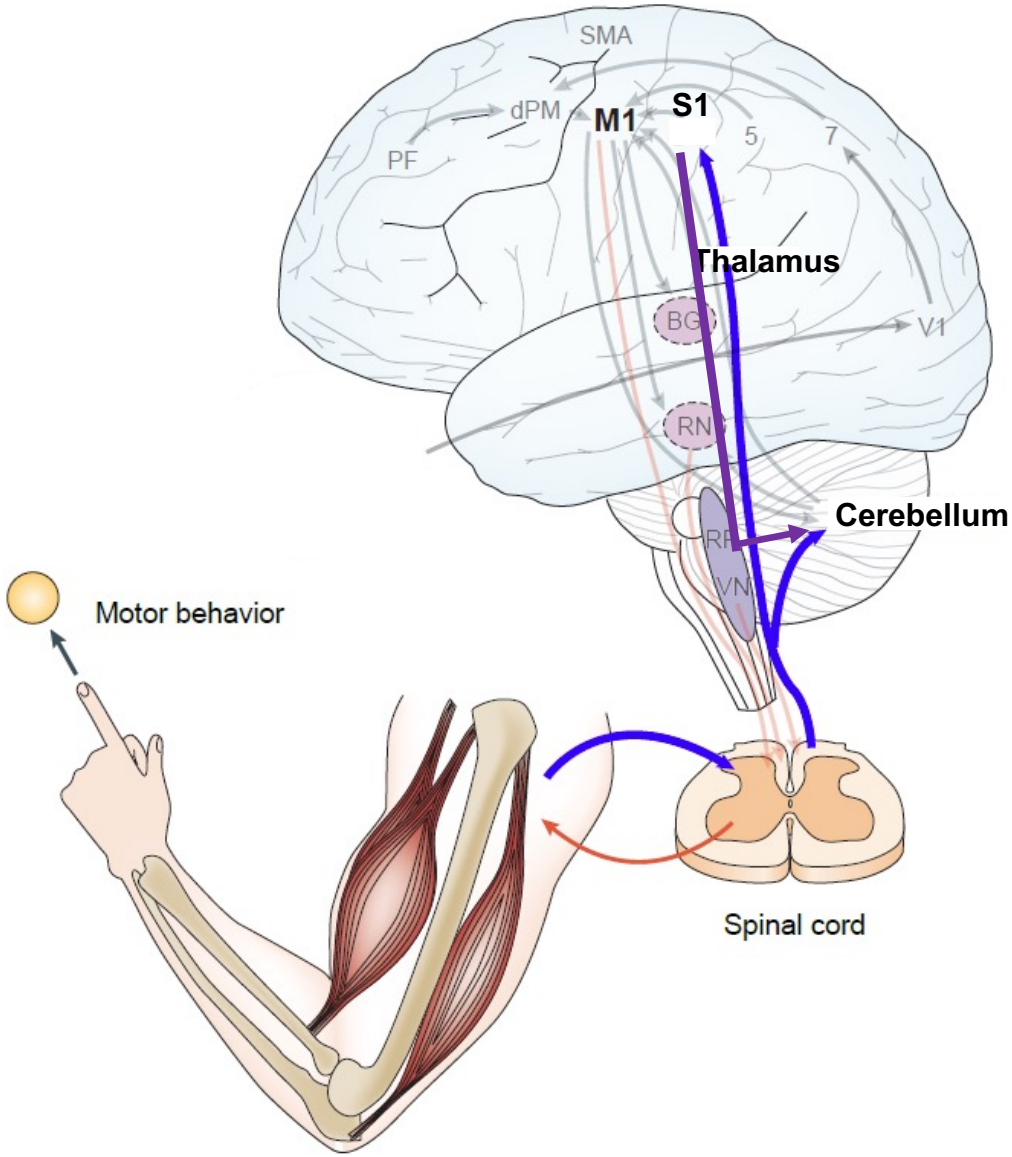


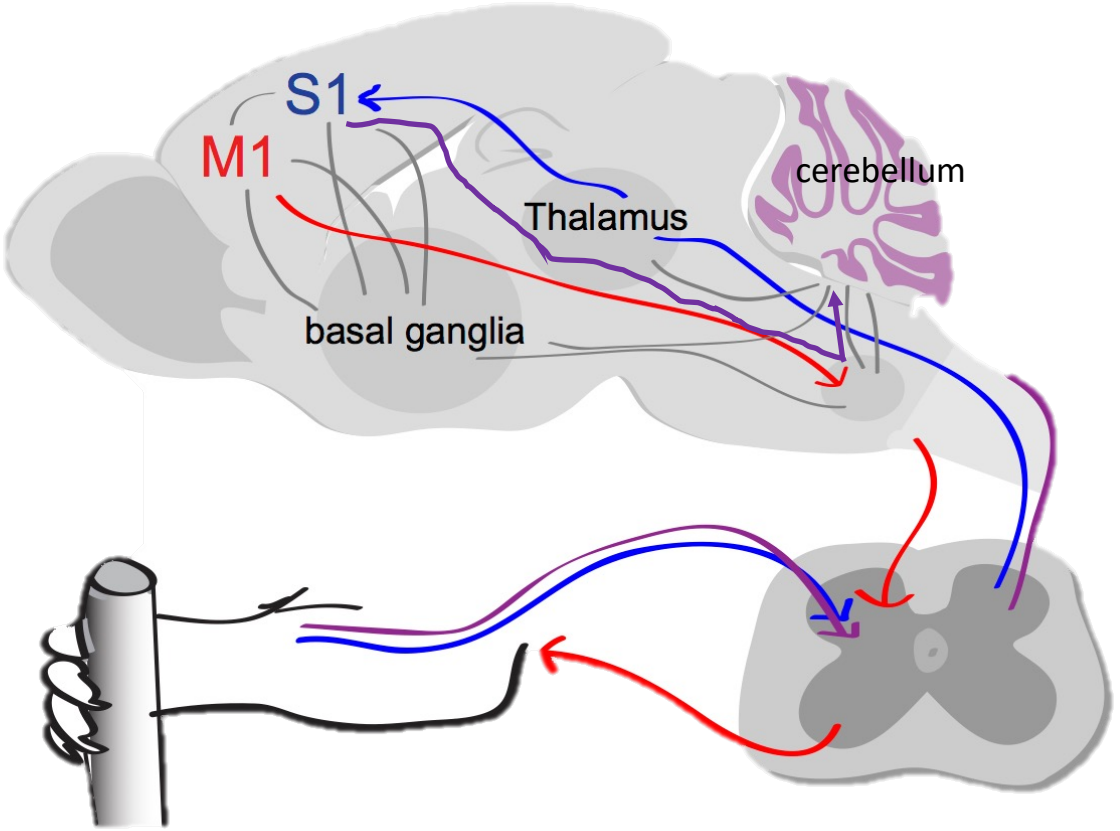


- Muscle spindles are primarily responsible for position and movement sense
- Golgi tendon organs provide the sense of force
- Feedback is essential for the accurate execution of movement execution

Neuroscience, 3rd Edition

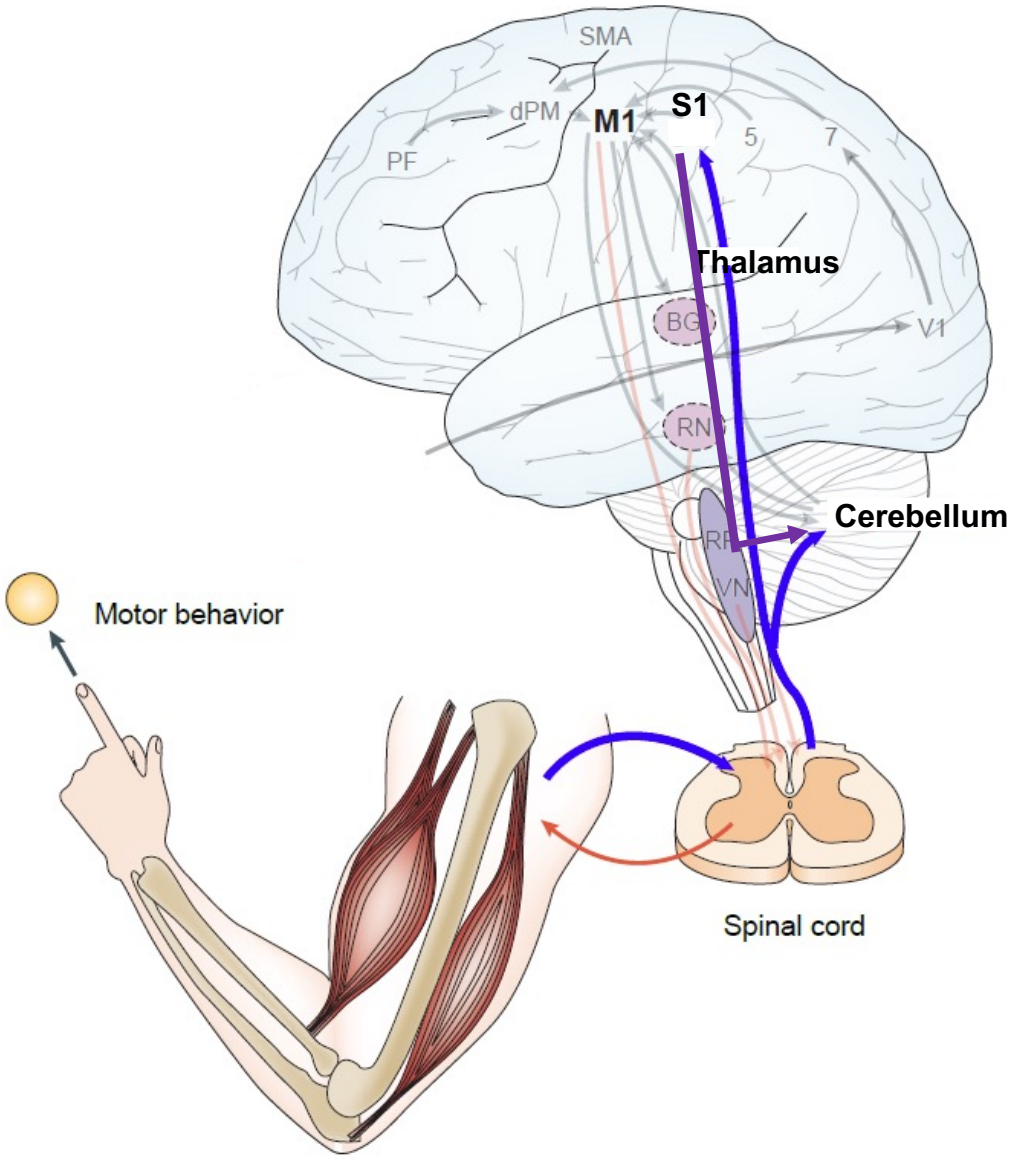
Into the brain: overview of the anatomy of feedback





Adapted from Scott, 2004

Proprioception: from muscles to the CNS



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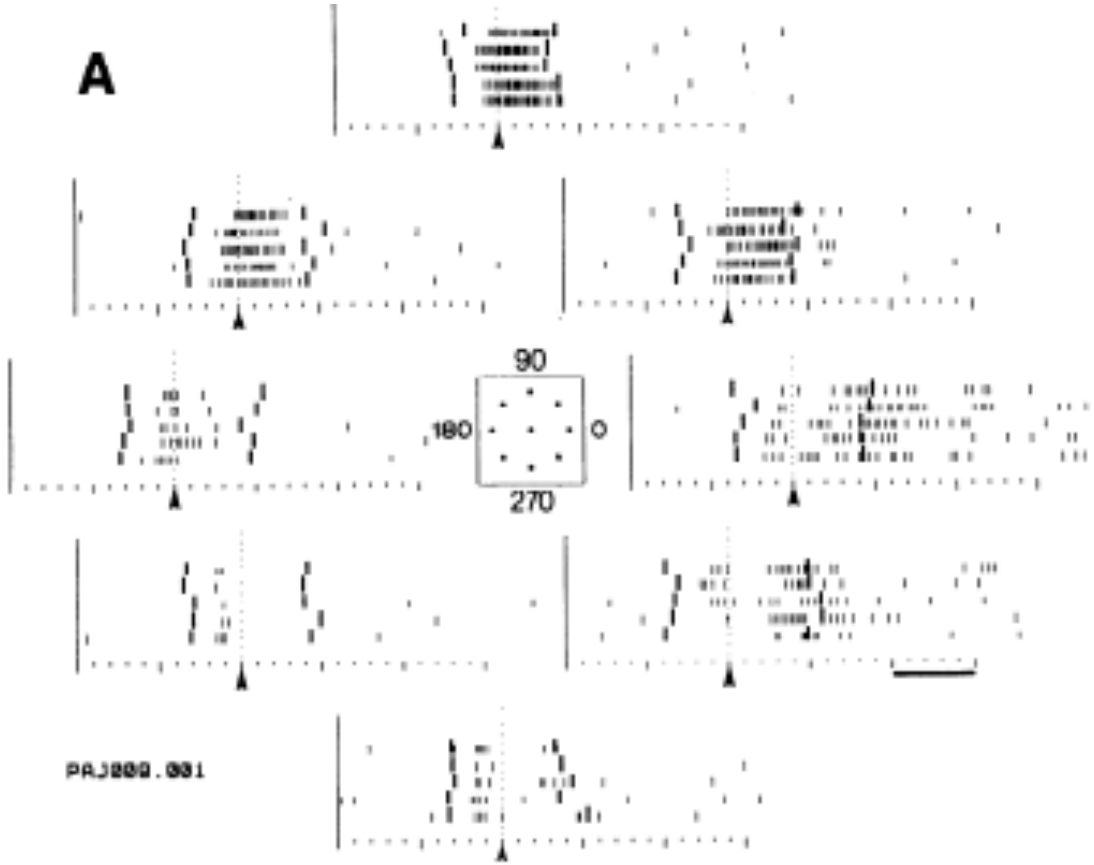
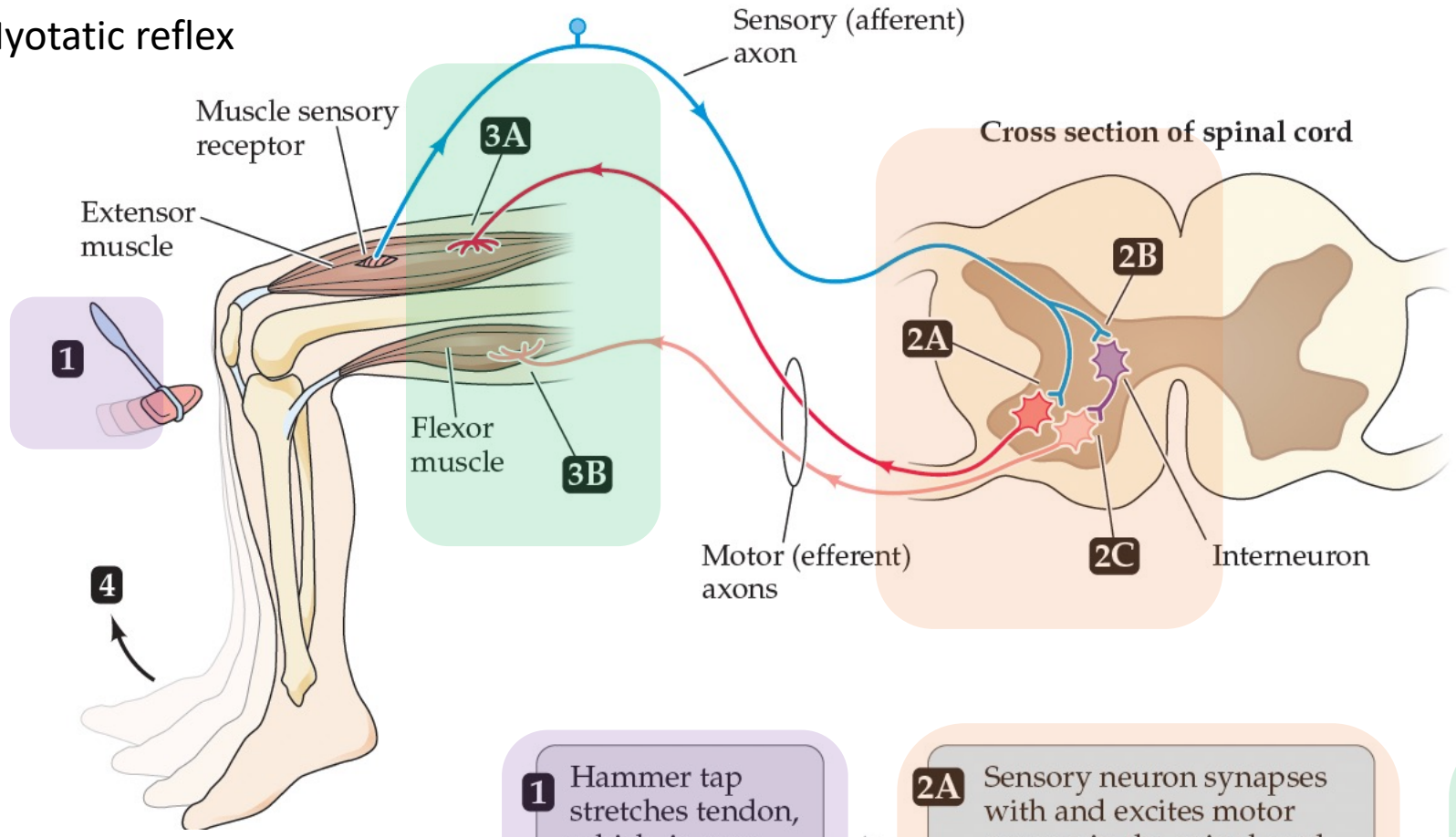
S1



M. J. Prud'homme and J. F. Kalaska 1994

Sensorimotor control: somatosensory feedback is critical

Myotatic reflex



1 Hammer tap stretches tendon, which, in turn, stretches sensory receptors in leg extensor muscle.

2A Sensory neuron synapses with and excites motor neuron in the spinal cord.

2B Sensory neuron also excites spinal interneuron.

2C Interneuron synapse inhibits motor neuron to flexor muscles.

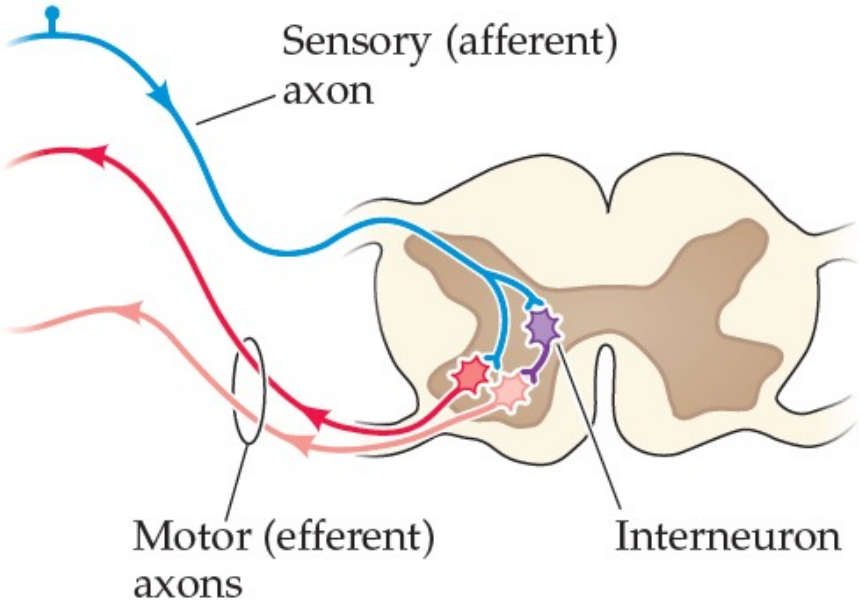
3A Motor neuron conducts action potential to synapses on extensor muscle fibers, causing contraction.

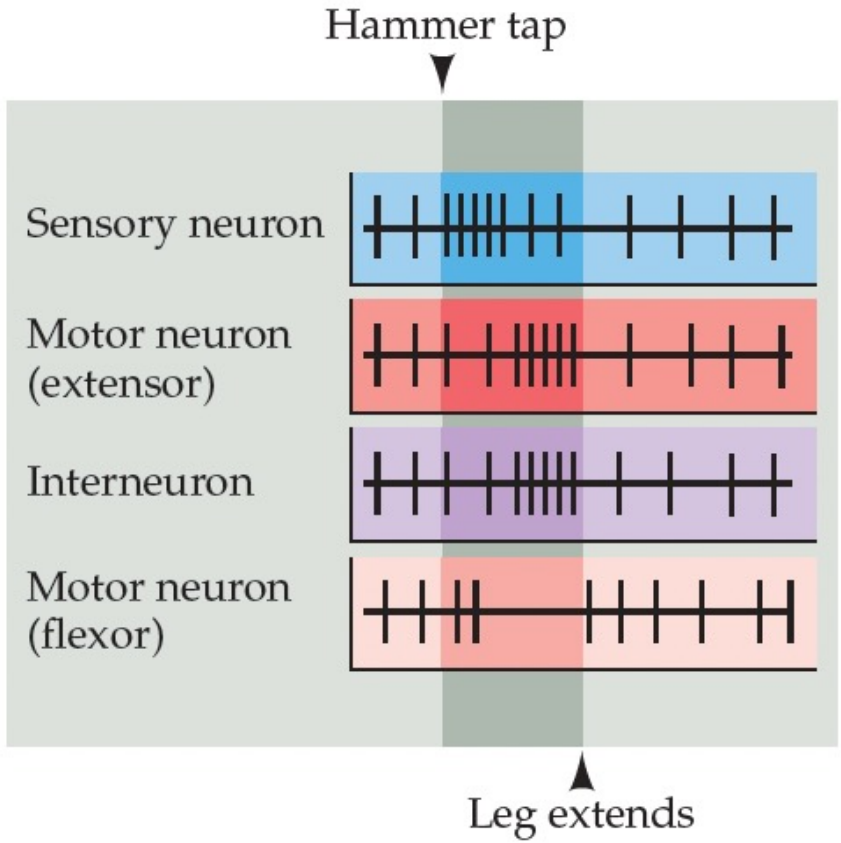
3B Flexor muscle relaxes because the activity of its motor neurons has been inhibited.

4 Leg extends.

CH 1, FIGURE 1.7

Sensorimotor control: somatosensory feedback is critical

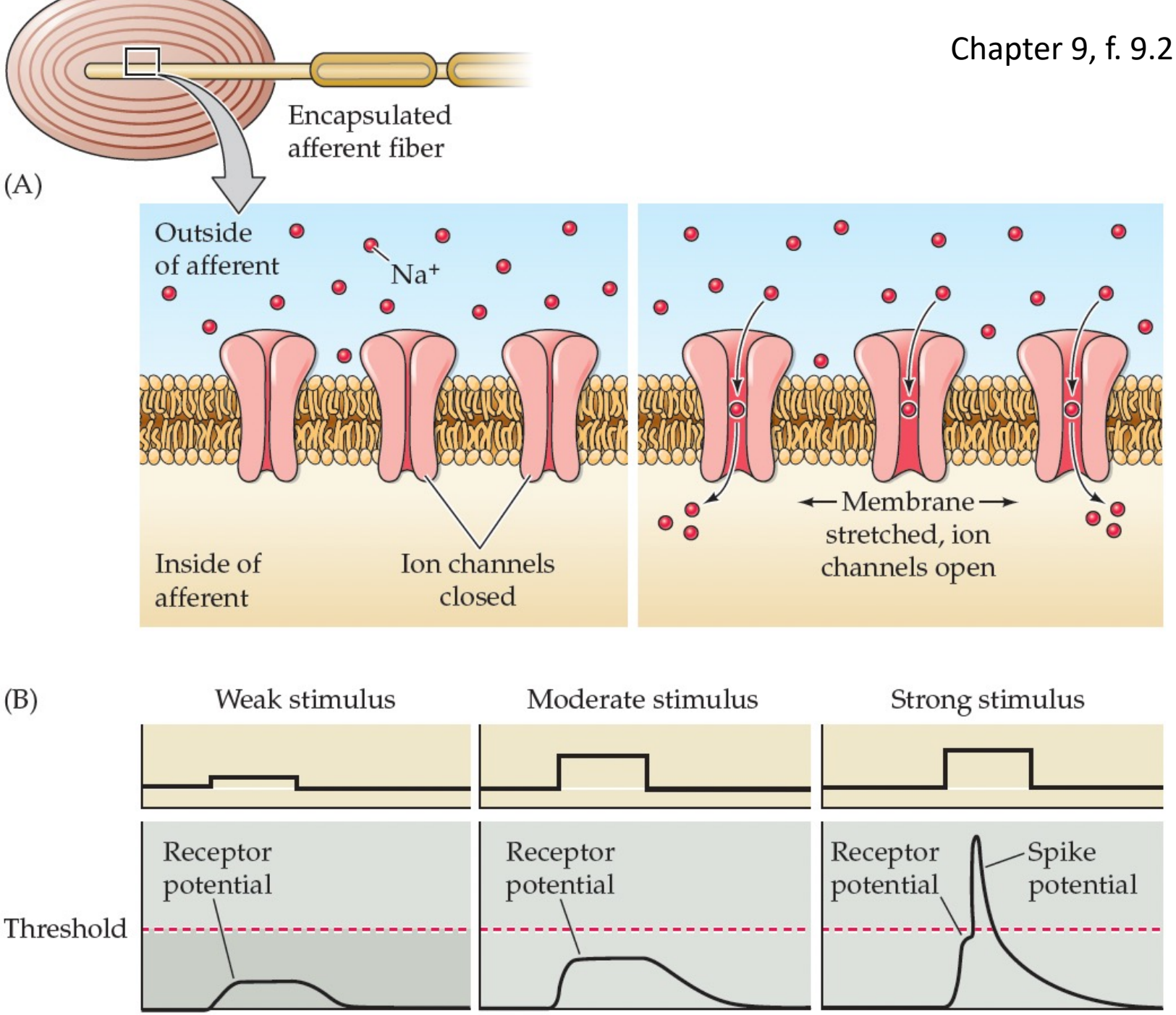




CH 1, FIGURE 1.8

Sensory transduction: across the somatosensory afferents

Chapter 9, f. 9.2



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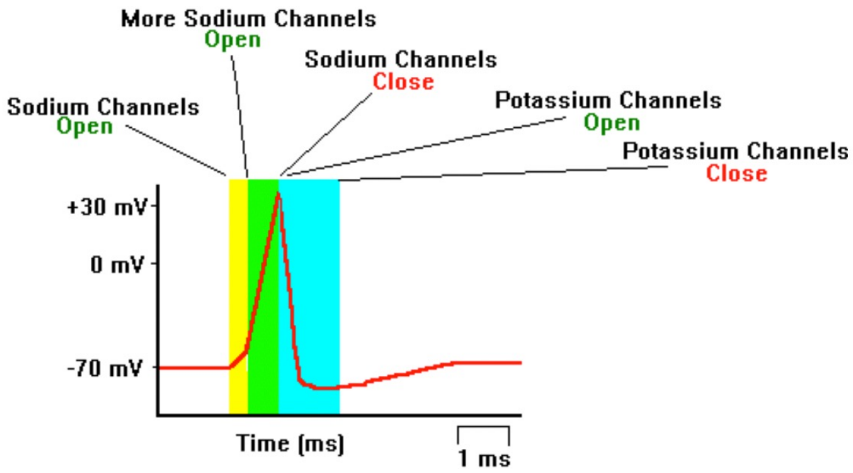
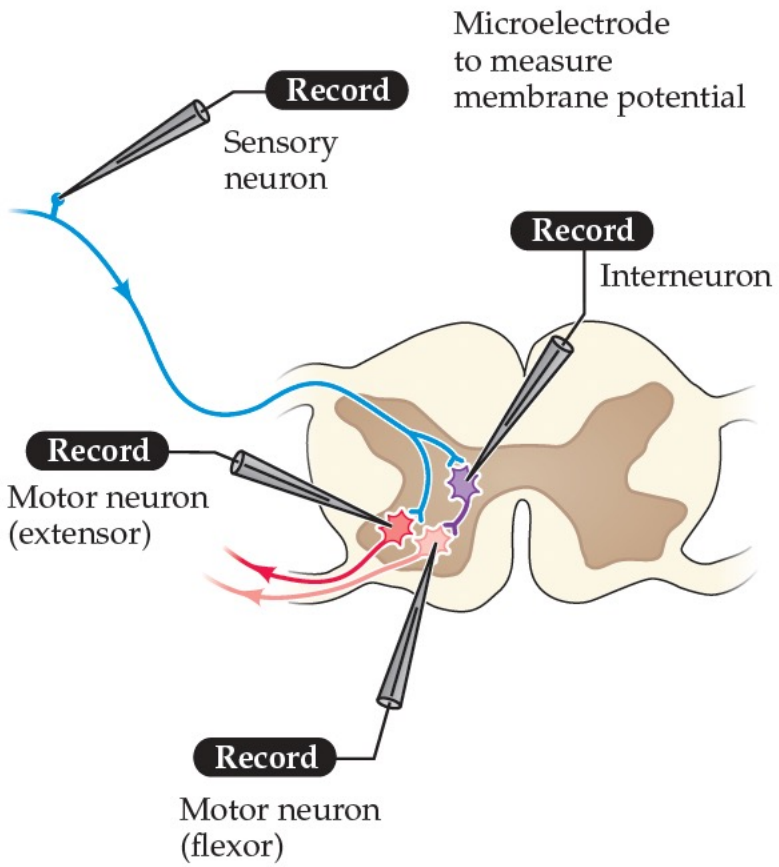
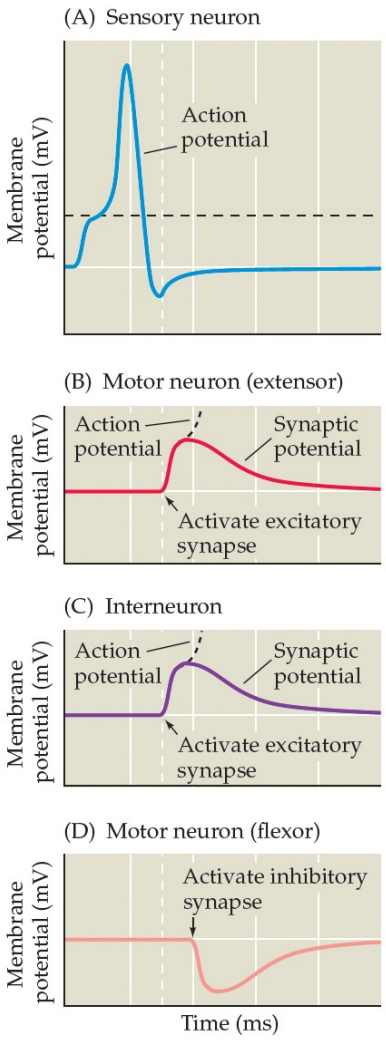
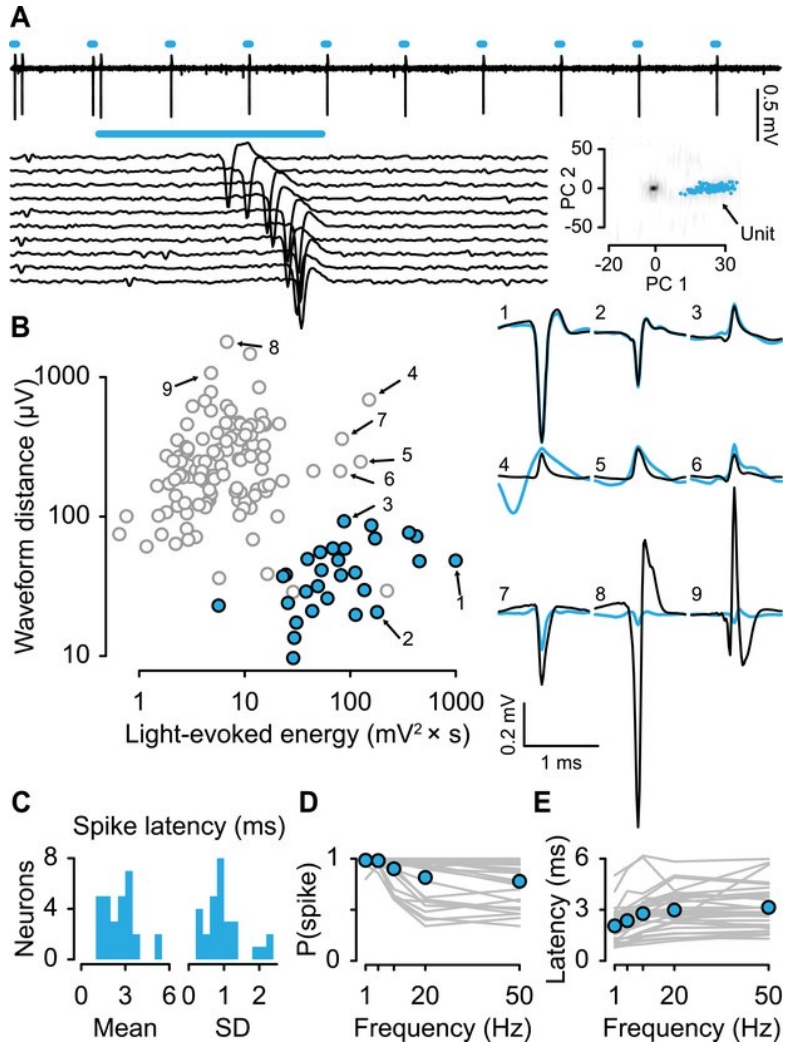


Reminder: a “spike’” is an action potential!





Real science example:
- spikes recorded in awake, behaving animals

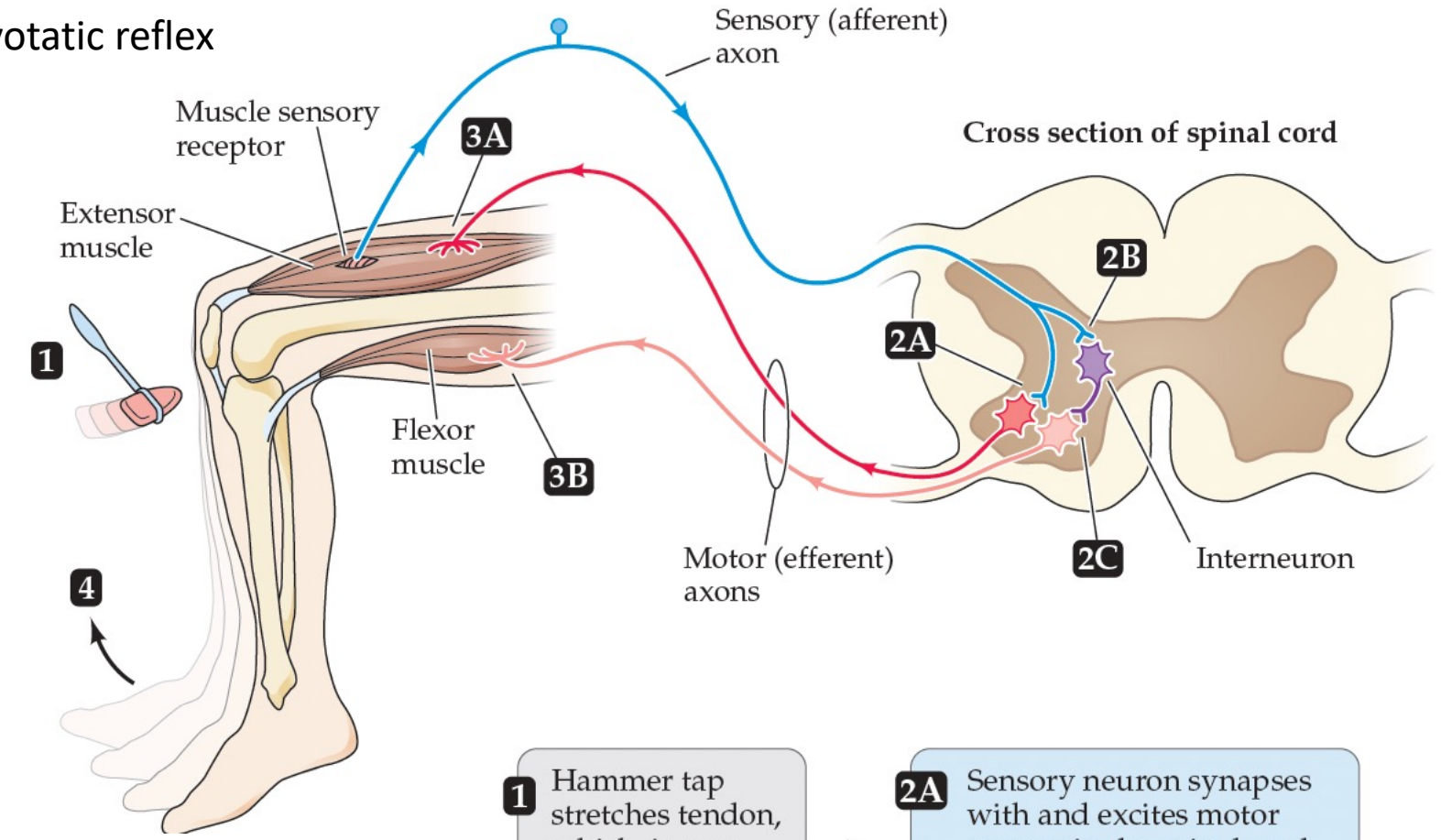


Cohen et al eLife 2015

CH 1, FIGURE 1.9

Sensorimotor control: somatosensory feedback is critical

Myotatic reflex



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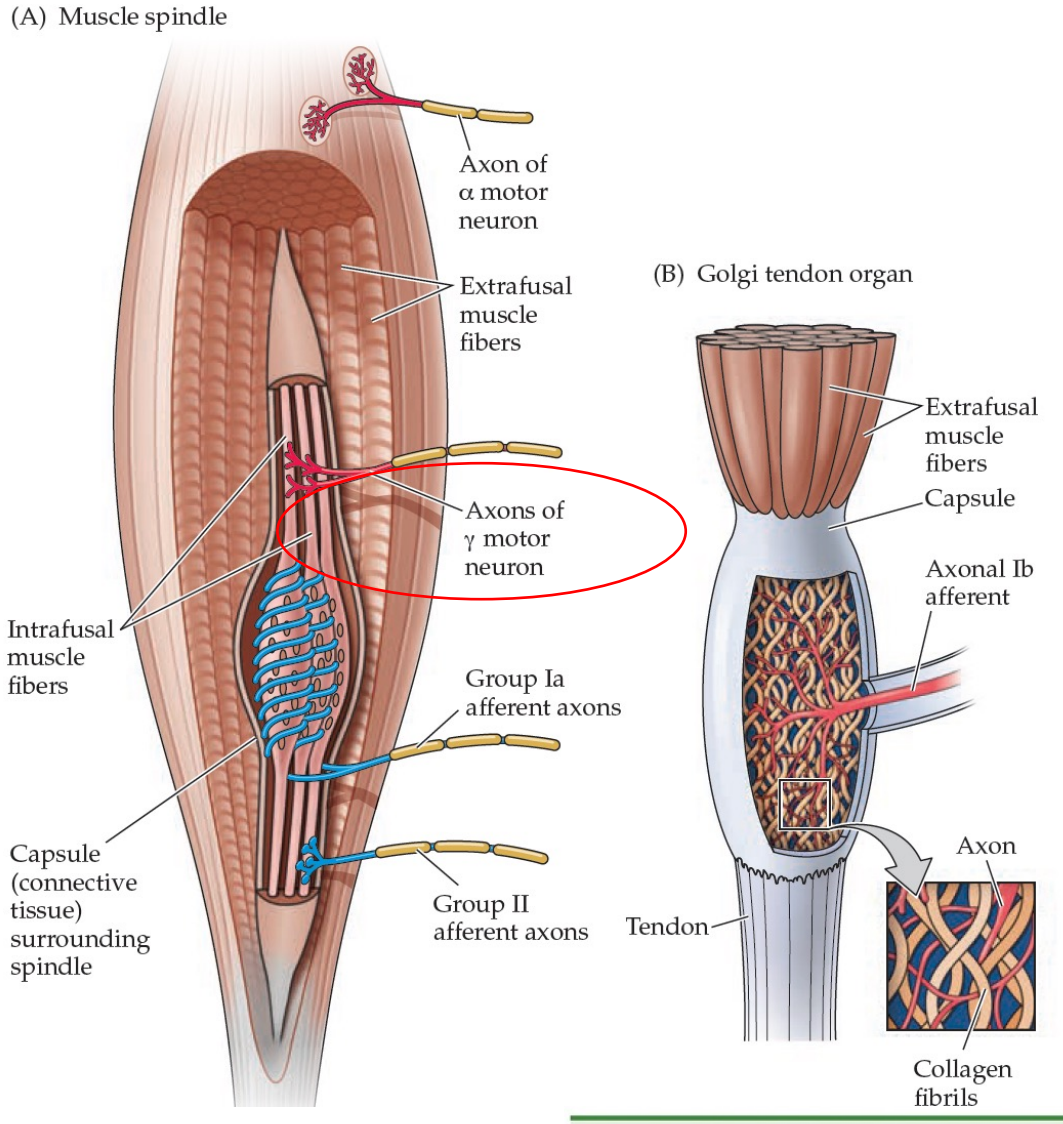
CH 1, FIGURE 1.7

Proprioception: from muscles to the CNS



afferent fiber:
Information is carried *from* periphery *to* the CNS

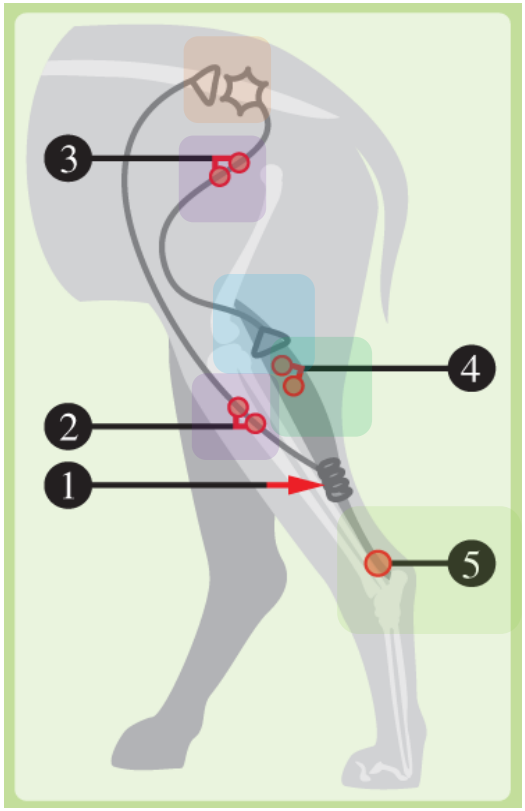
efferent fiber:
carries information *from* the CNS *towards* the periphery (makes an effect in the p.)

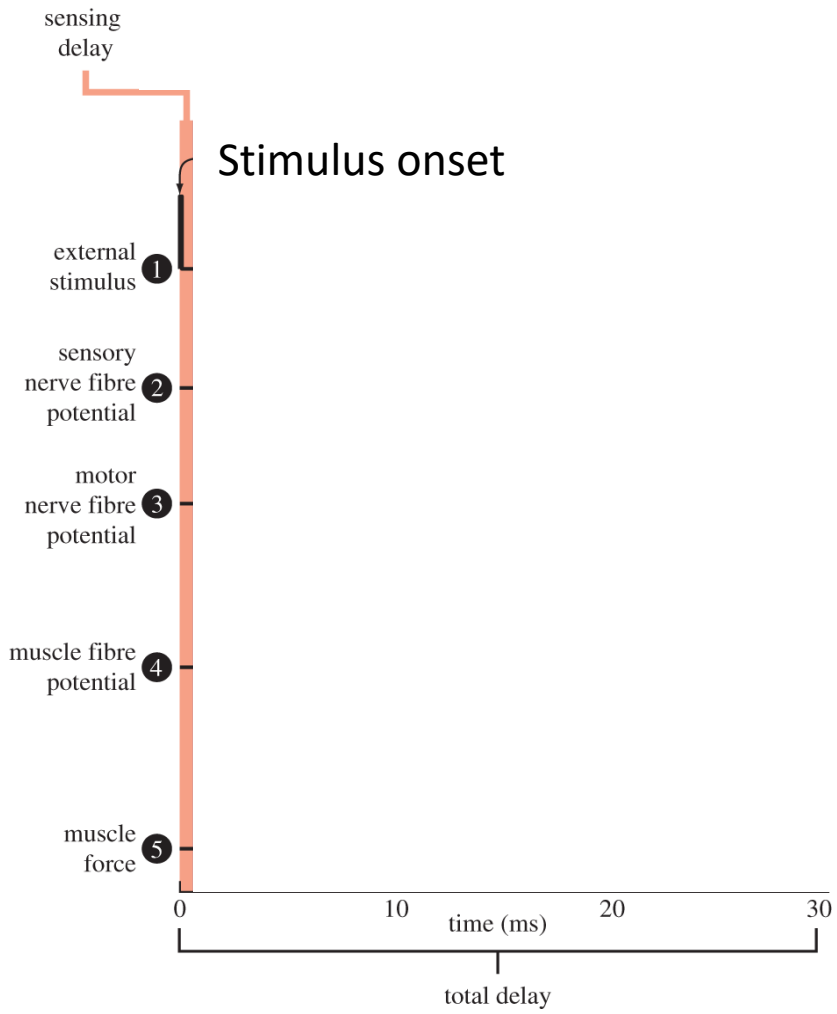
That's 288 - 432 kilometer per hour!

Sensory function	Receptor type	Afferent axon type[a]	Axon diameter	Conduction velocity
Proprioception	Muscle spindle	Ia, II	13–20 μm	80–120 m/s

CH 9, FIGURE 9.7

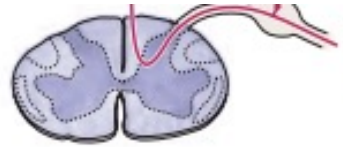
The stretch reflex: how long does it take to act?



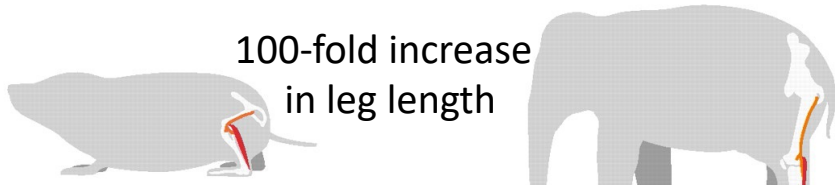


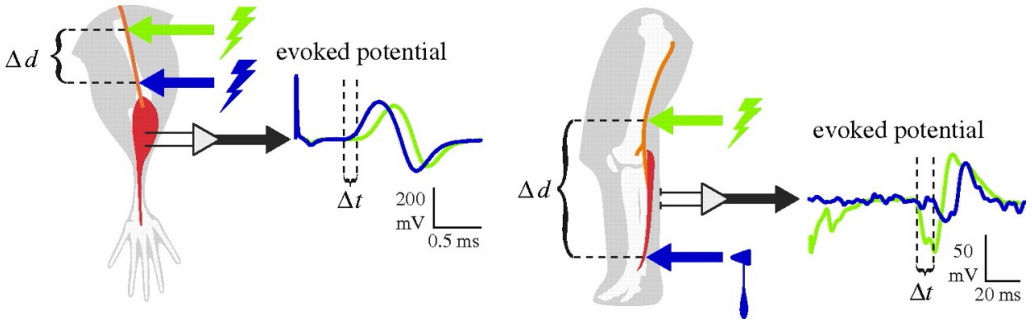
Adapted from Scaling of sensorimotor delays in terrestrial mammals. DOI: (10.1098/rspb.2018.0613)

Feedback delays in biology: from shrews to elephants

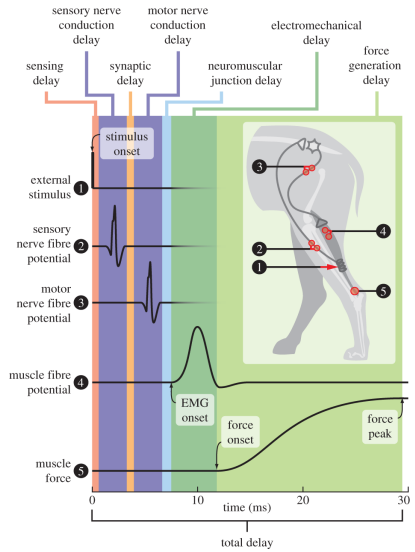


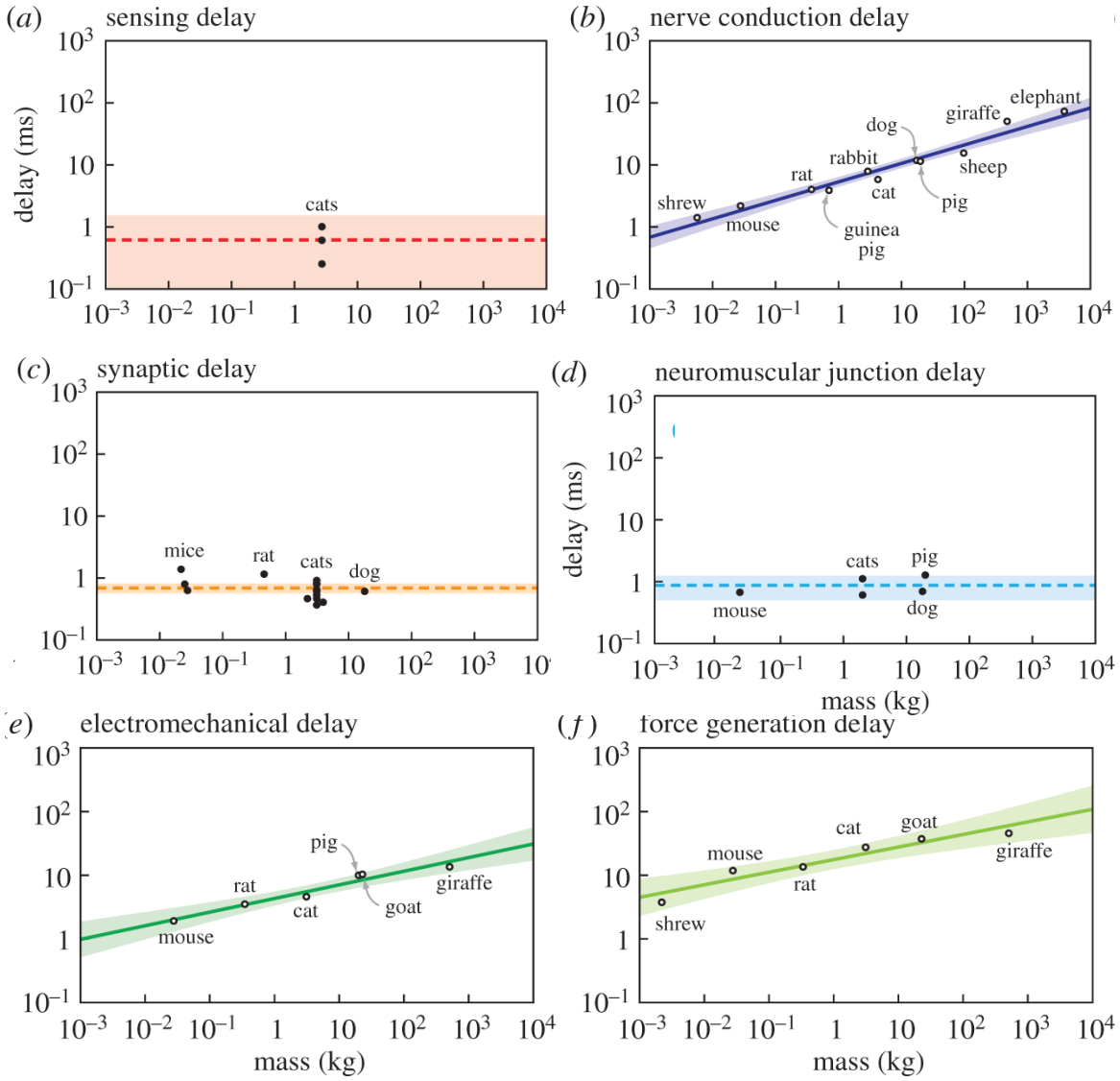
100-fold increase in leg length





nerve conduction delay increases rapidly with animal size





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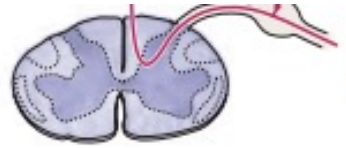
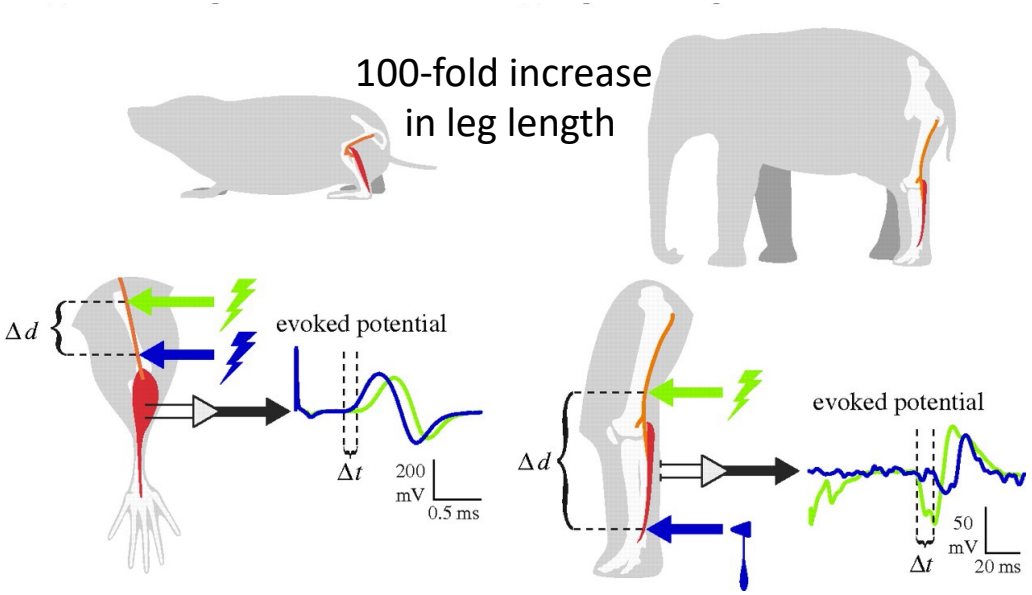
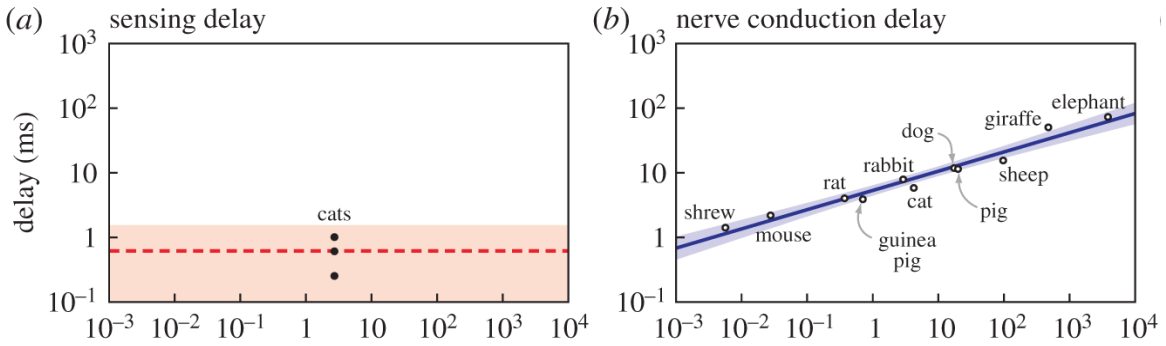
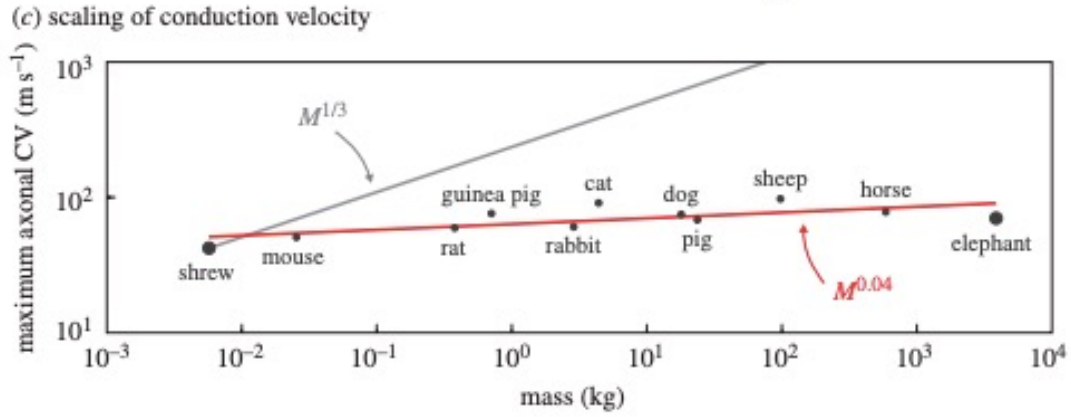






- Conduction velocity (cv) was nearly constant, increasing proportionally with **mass to the 0.04 power**



- larger animals are burdened with relatively long physiological delays
- Implications for behavior, & requirements for prediction to help control movements

Adapted from Scaling of sensorimotor delays in terrestrial mammals. DOI: (10.1098/rspb.2018.0613)

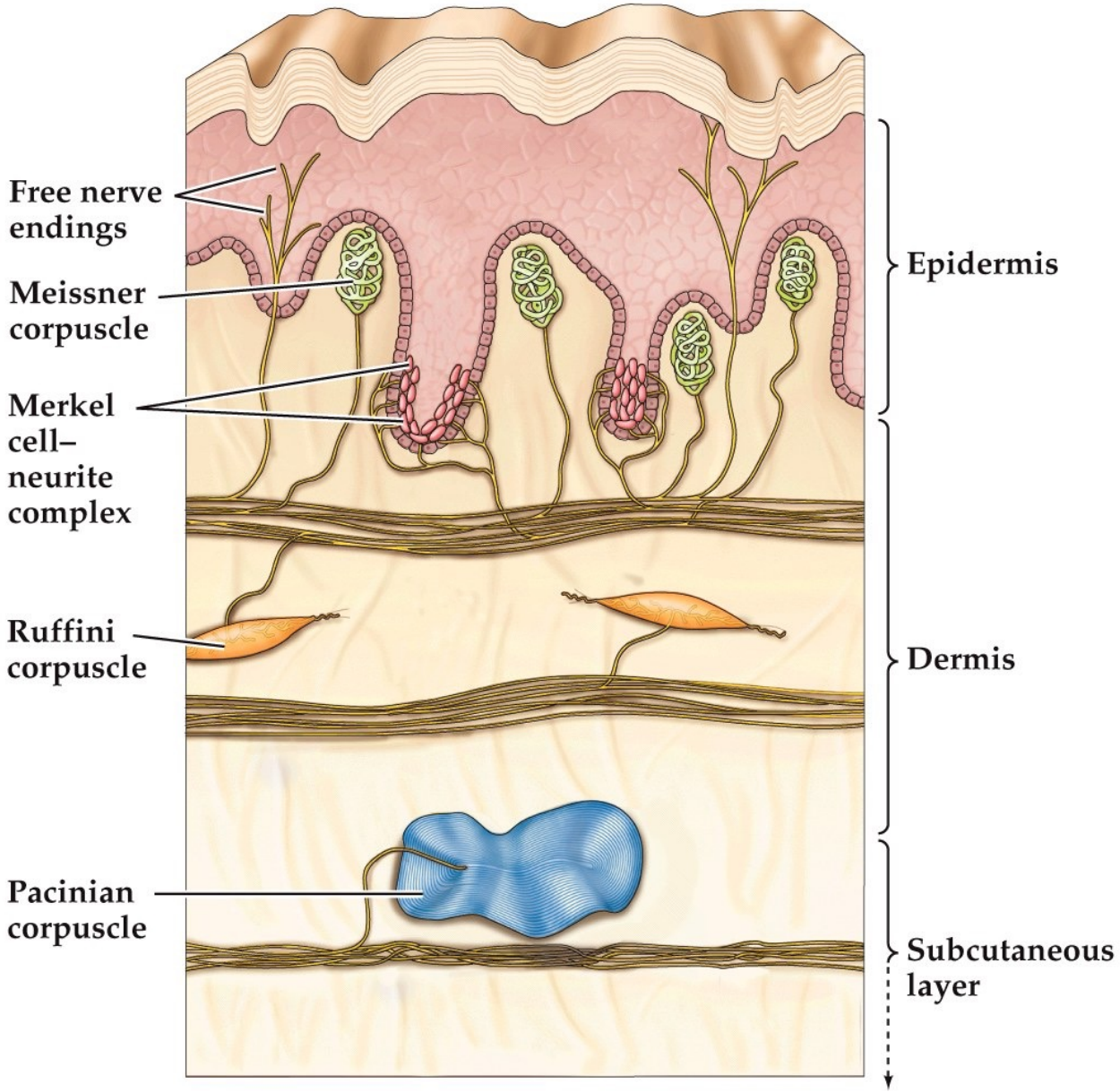
1997 BBC documentary, *The Man Who Lost His Body*.

https://www.dailymotion.com/video/x12647t

Why don't you constantly feel your clothes on your body?

Touch ….

Different types of mechanoreceptors in skin ("cutaneous mechanoreceptors")



Free nerve endings
(esp. important for *pain* sensation)

Meissner's corpuscles
3-40 Hz (low frequency)

Merkel cell afferents
slowly adapting; highest spatial resolution

Rufini's endings
(- corpuscles)

Pacinian corpuscles
(250 -350 Hz)
High sensitivity (10 nm)

Chapter 9 Fig. 9.5

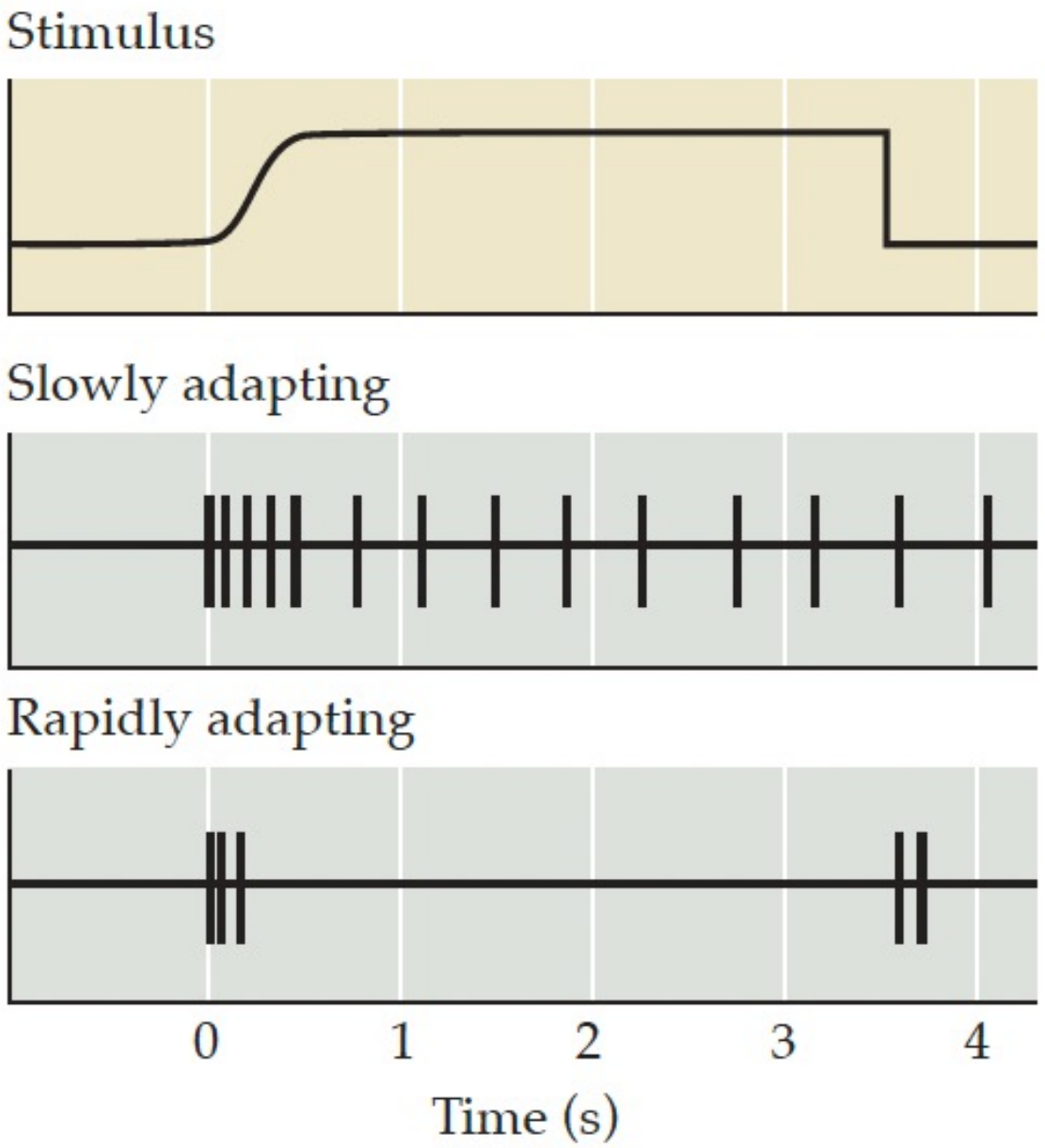
Slide courtesy of R.S.

Why don't you constantly feel your clothes on your body?

Slowly adapting receptors continue responding to a stimulus

Rapidly adapting receptors respond only at the onset (and often the offset) of stimulation.

These functional differences allow mechanoreceptors to provide information about both the static (via slowly adapting receptors) and dynamic (via rapidly adapting receptors) qualities of a stimulus.



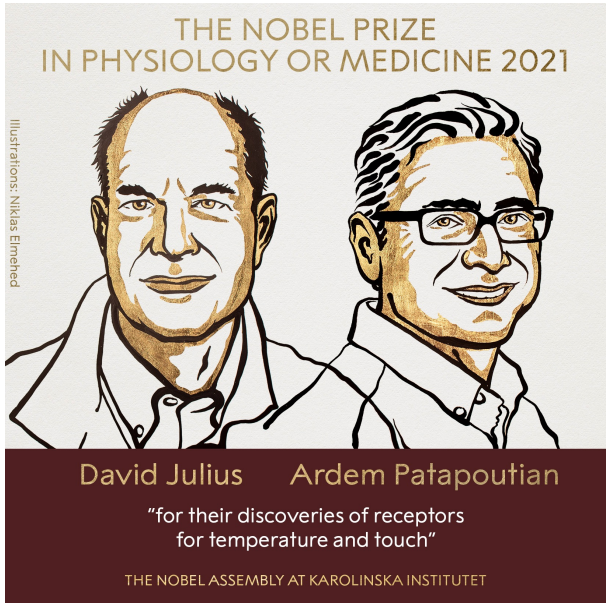
Chapter 9, f. 9.4

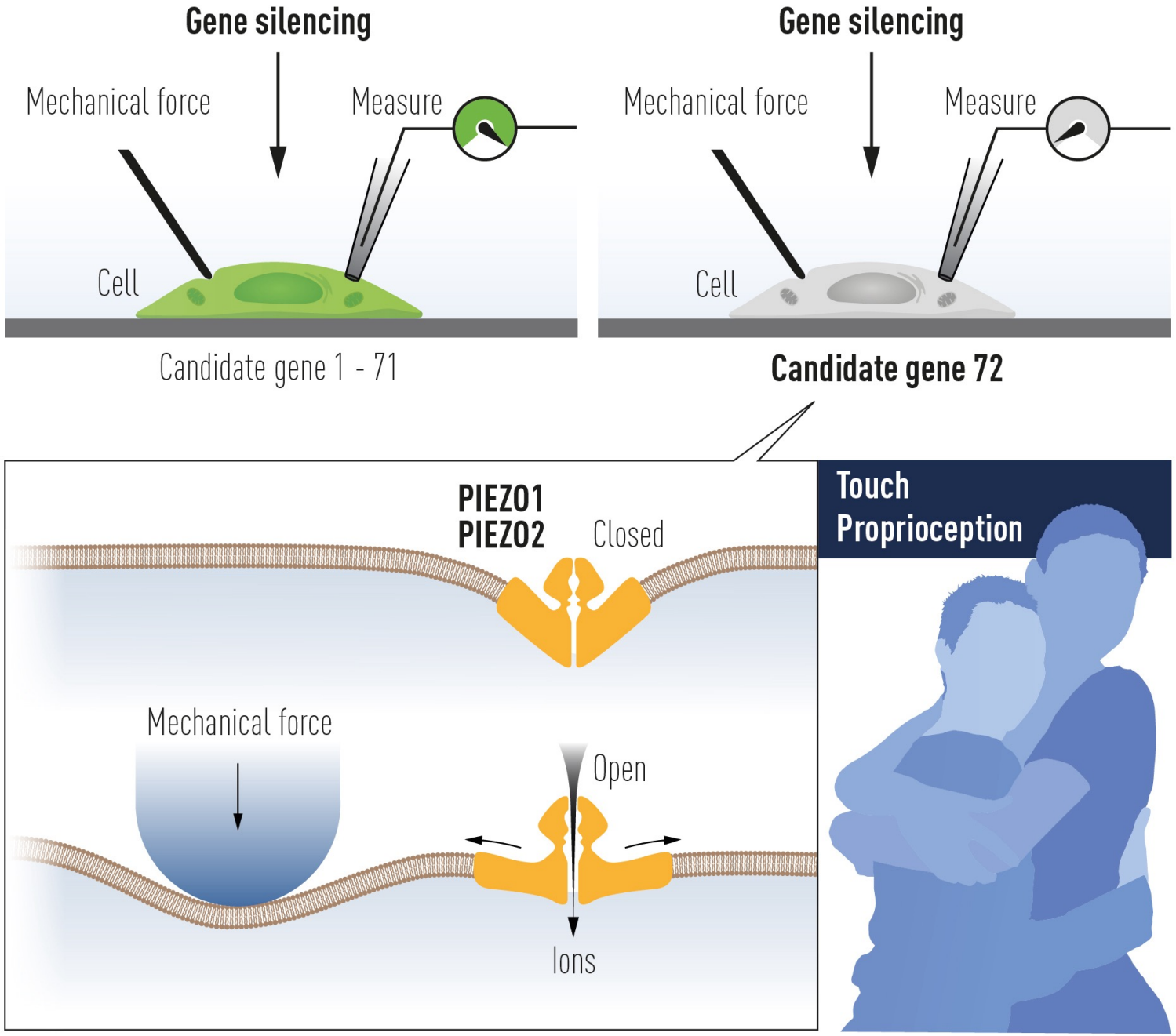
Different types of mechanoreceptors in skin ("cutaneous mechanoreceptors")

TABLE 9.2 ■ Afferent Systems and Their Properties

	Small receptive field		Large receptive field	
	Merkel	**Meissner**	**Pacinian**	**Ruffini**
Location	Tip of epidermal sweat ridges	Dermal papillae (close to skin surface)	Dermis and deeper tissues	Dermis
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	Shape and texture perception	Motion detection; grip control	Perception of distant events through transmitted vibrations; tool use	Tangential force; hand shape; motion direction
Effective stimuli	Edges, points, corners, curvature	Skin motion	Vibration	Skin stretch
Receptive field area[a]	9 mm^2	22 mm^2	Entire finger or hand	60 mm^2
Innervation density (finger pad)	100/cm^2	150/cm^2	20/cm^2	10/cm^2
Spatial acuity	0.5 mm	3 mm	10+ mm	7+ mm
Response to sustained indentation	Sustained (slow adaptation)	None (rapid adaptation)	None (rapid adaptation)	Sustained (slow adaptation)

Piezo1 and Piezo2 are essential components of distinct mechanically activated cation channels





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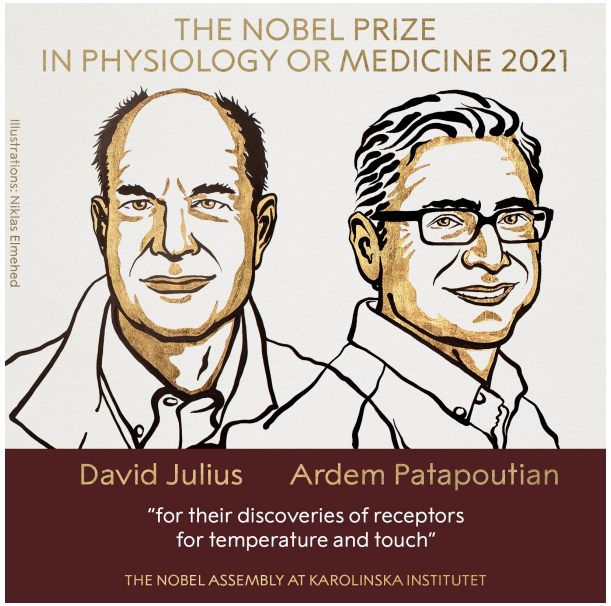
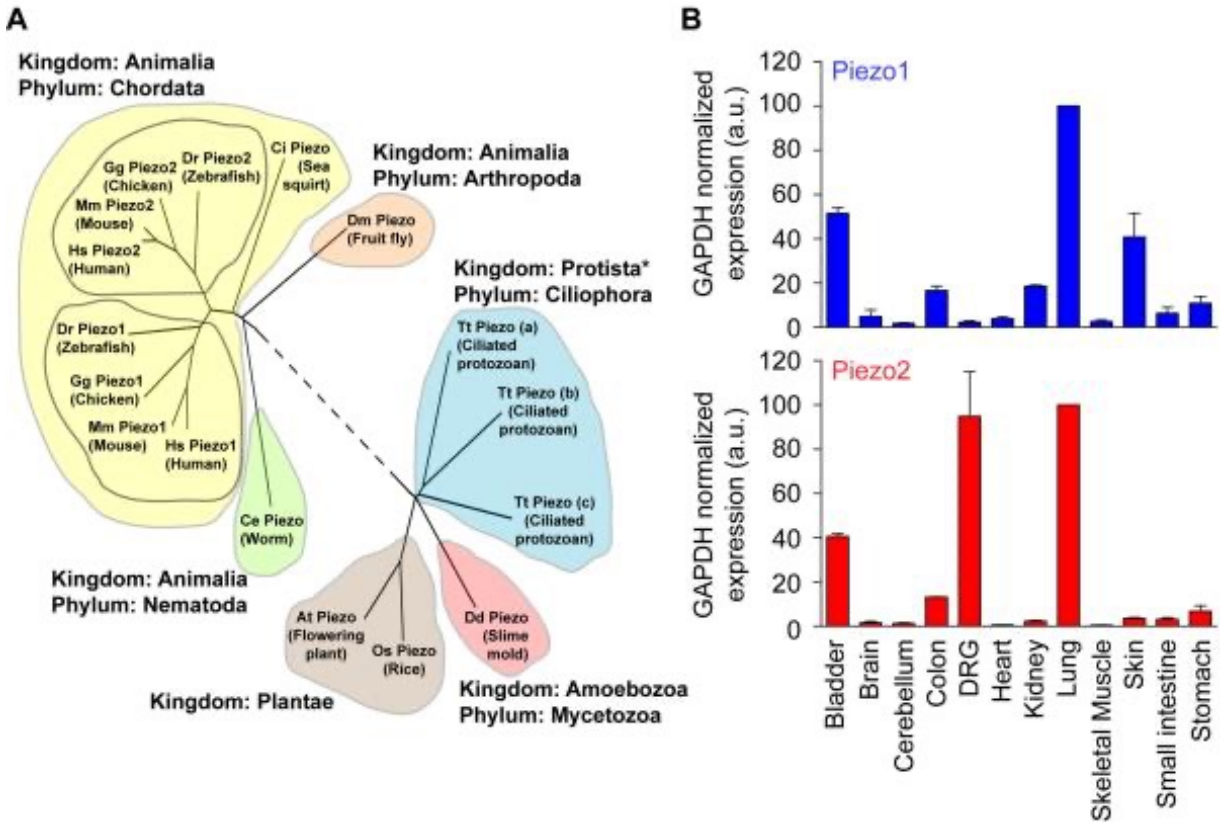


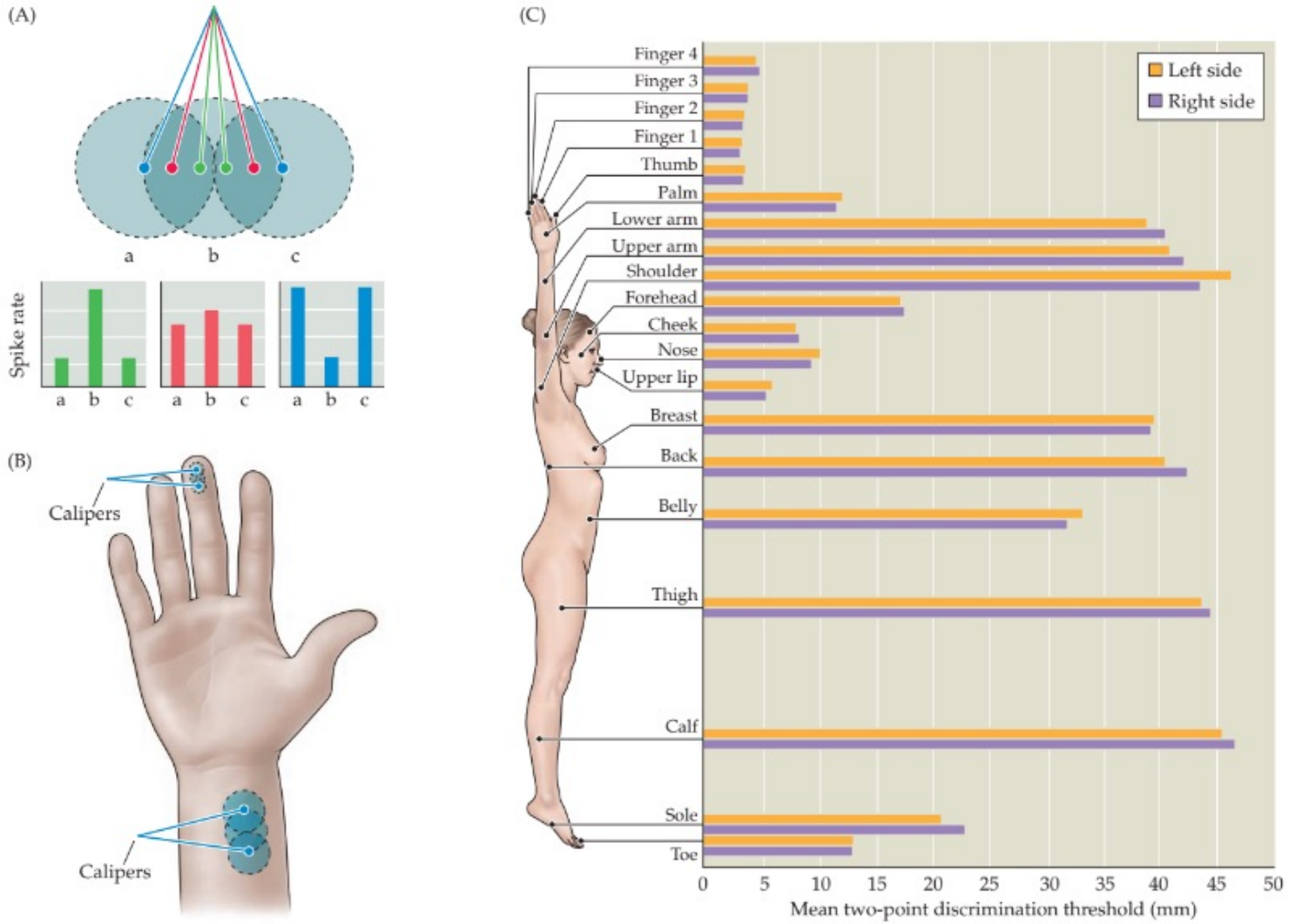


› Science. 2010 Oct 1;330(6000):55-60. doi: 10.1126/science.1193270. Epub 2010 Sep 2.

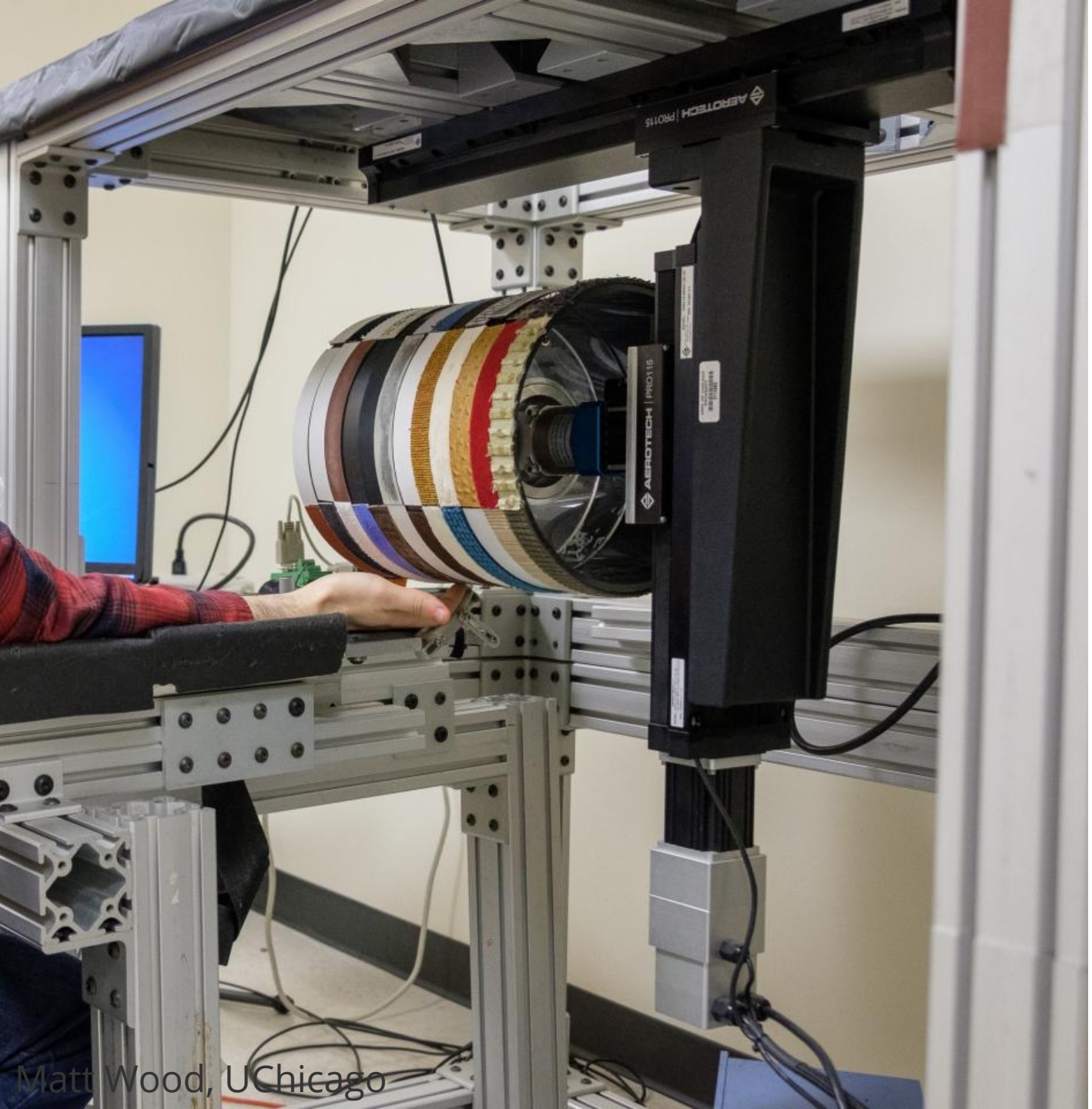
Piezo1 and Piezo2 are essential components of distinct mechanically activated cation channels

Bertrand Coste [1], Jayanti Mathur, Manuela Schmidt, Taryn J Earley, Sanjeev Ranade, Matt J Petrus, Adrienne E Dubin, Ardem Patapoutian

The two-point discrimination test for spatial mapping



Receptive fields and the two-point discrimination threshold.
Figure 9.3



Matt Wood, UChicago

How do neuroscientists study touch?

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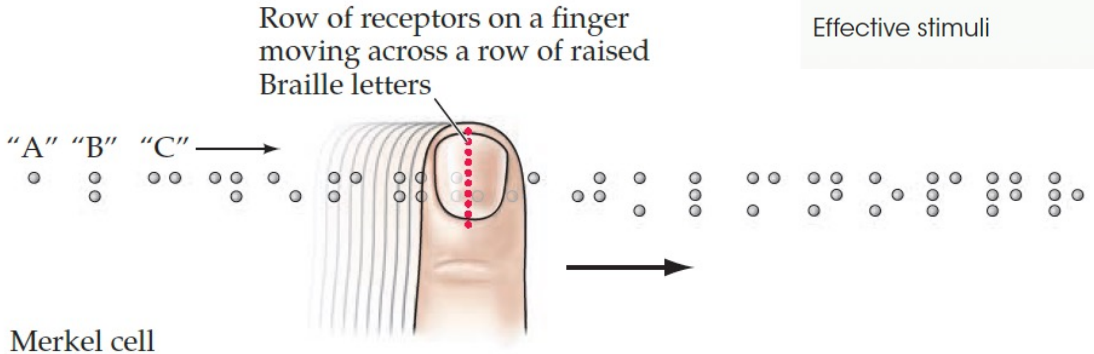
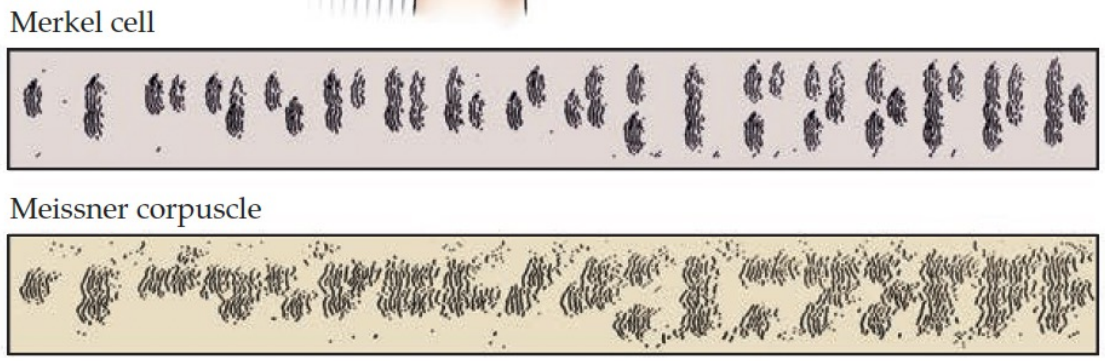
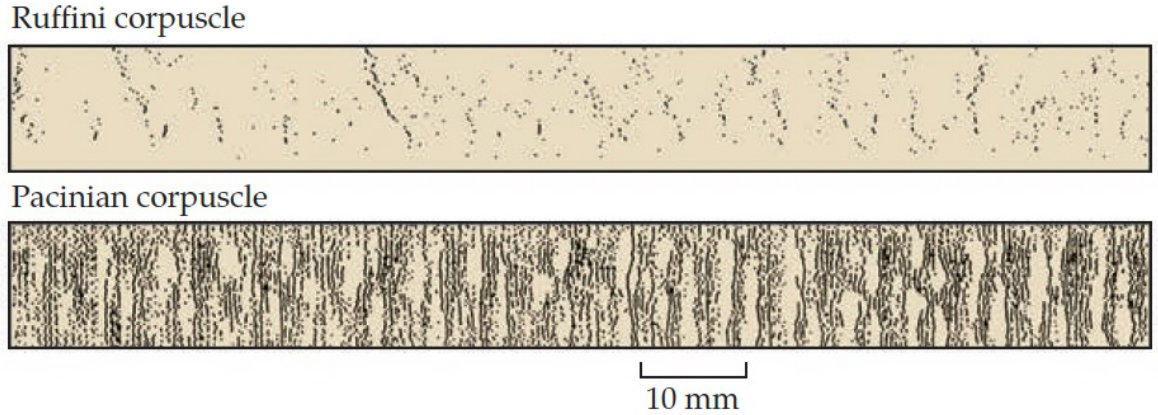
Effective stimuli	Edges, points, corners, curvature	Skin motion	Vibration	Skin stretch

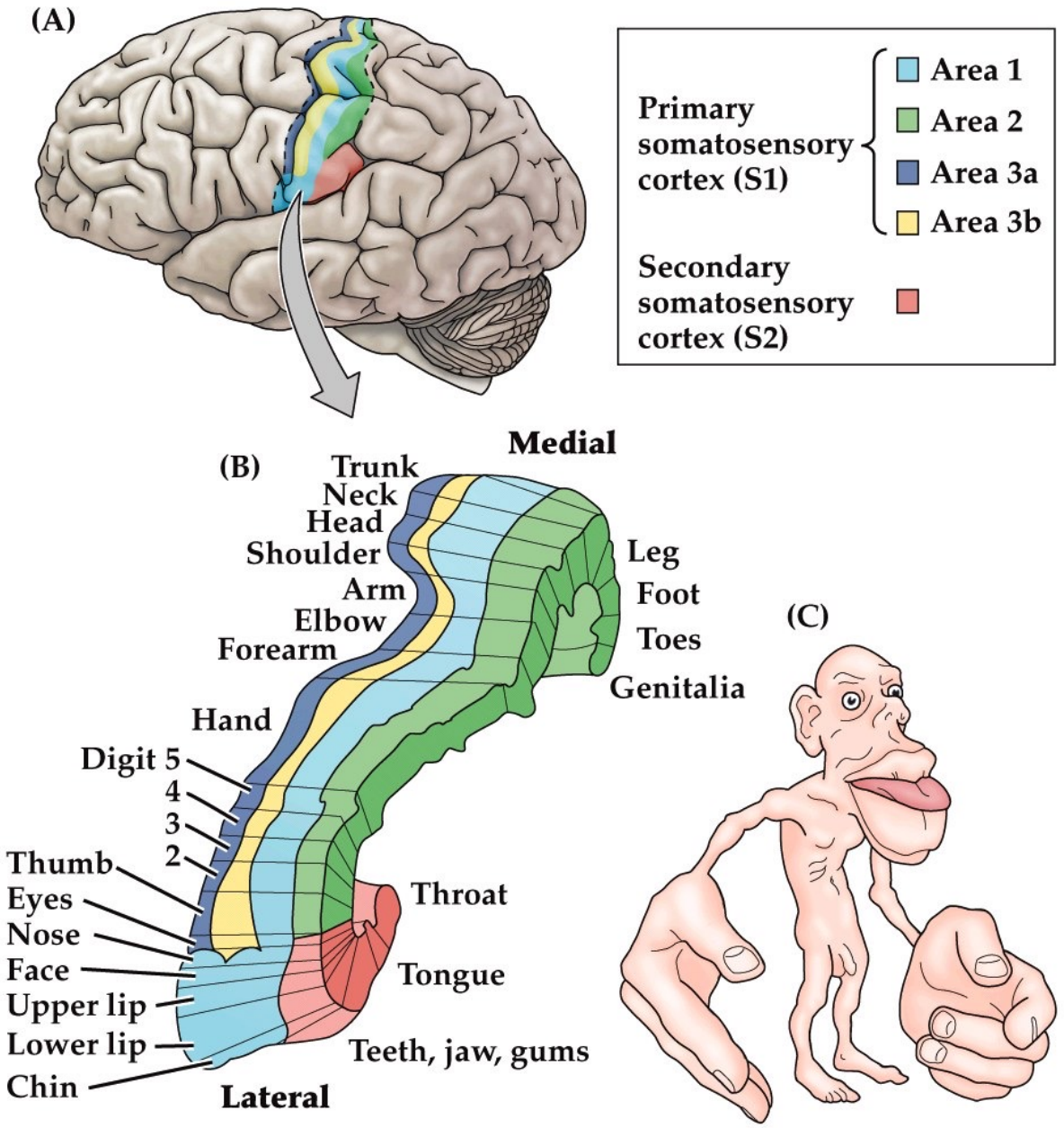




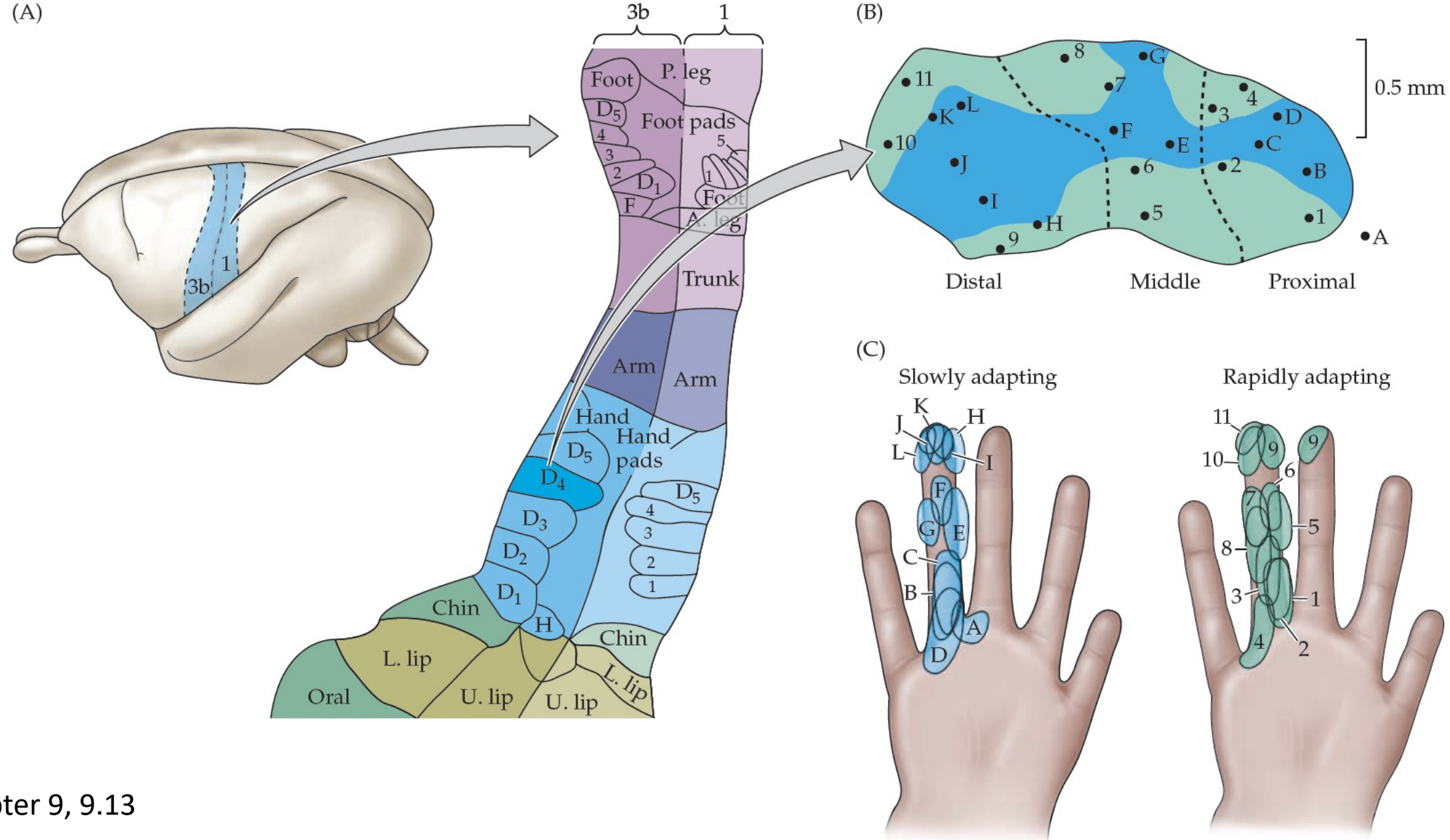


activity patterns in different mechanosensory afferents in the fingertip

Somatotopic order in the human primary somatosensory cortex



Neurons in the primary somatosensory cortex form functionally distinct columns



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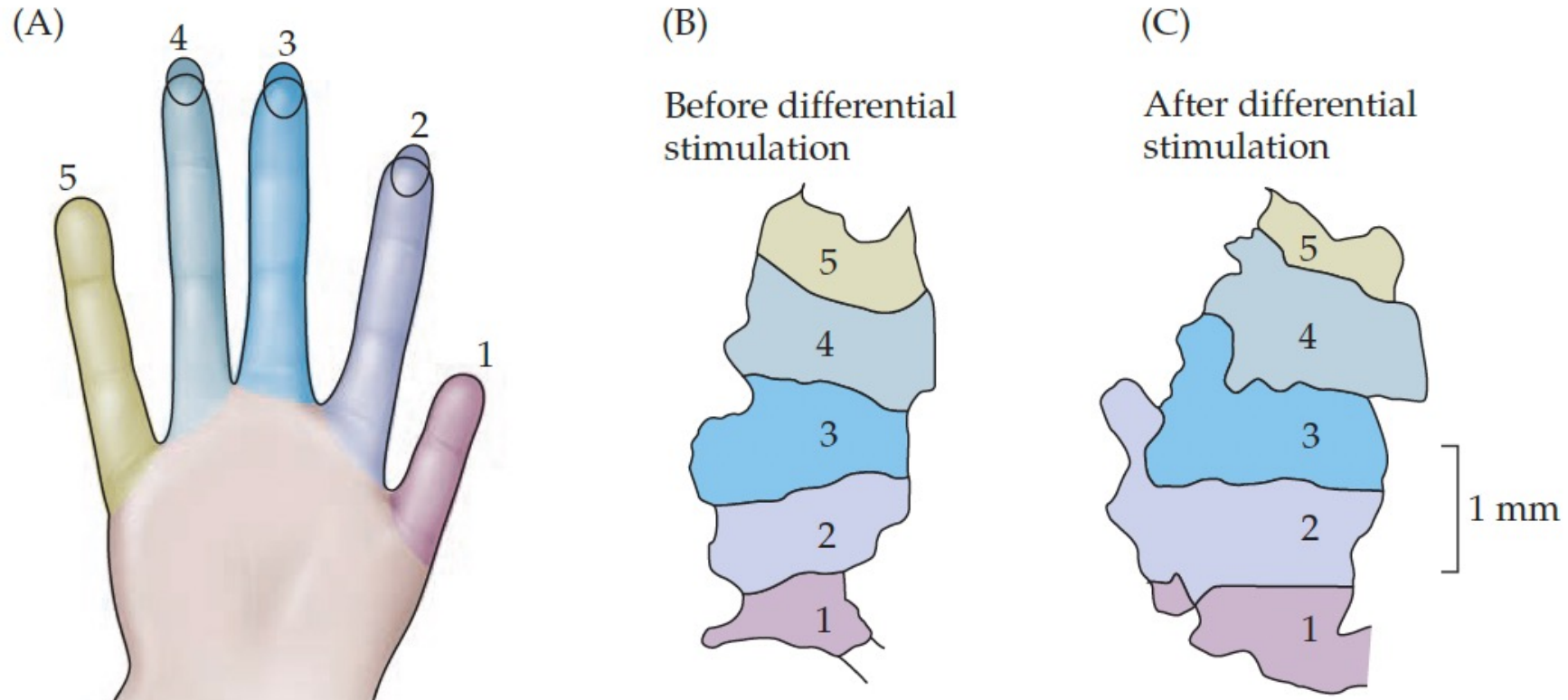
Functional expansion of a cortical representation by a repetitive behavioral task.



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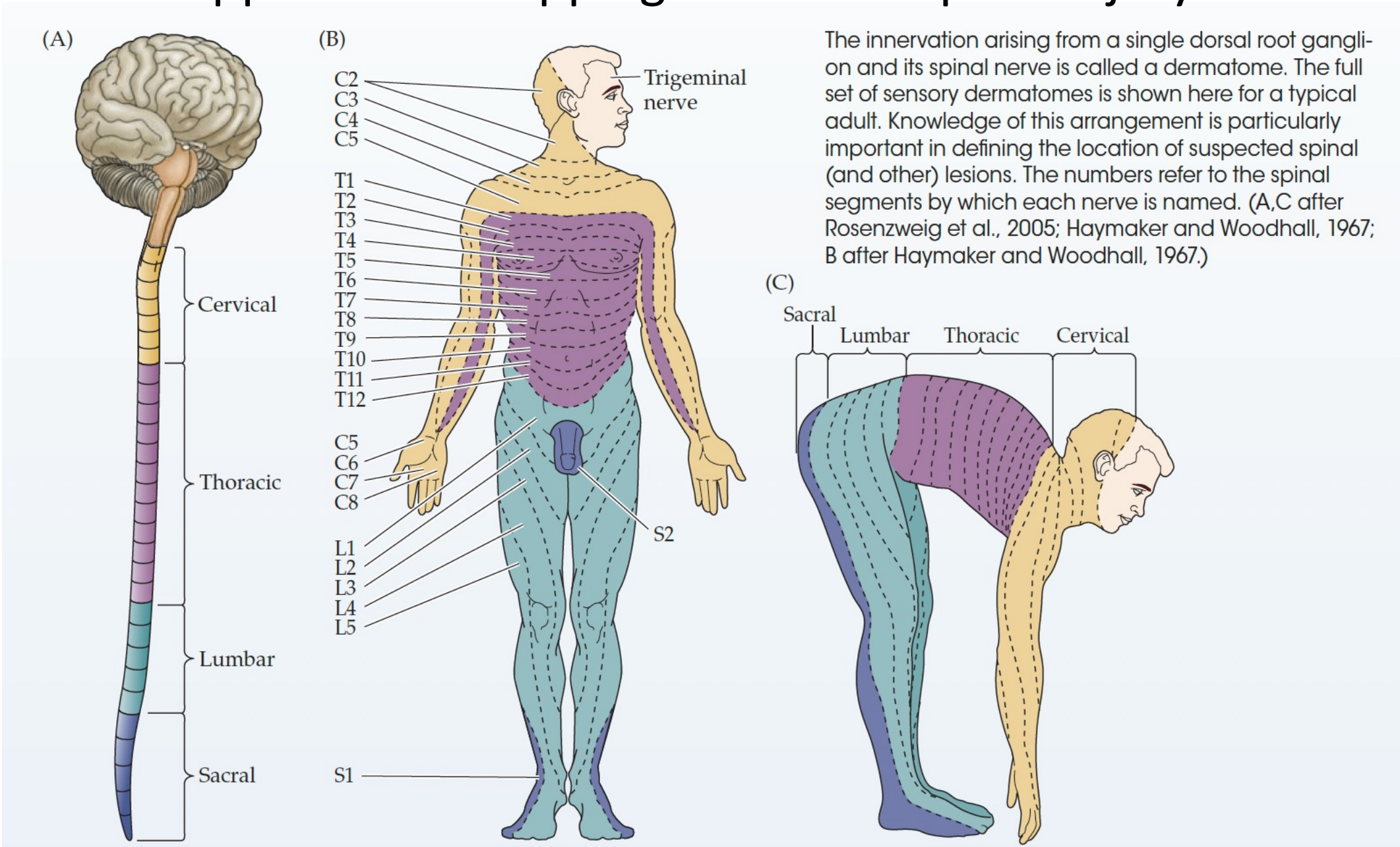
Clinical application: mapping deficits to spinal injury location




The cutting-edge:
Designing new neuroprosthetics to enable touch and proprioception in amputees
learn more from Prof. Micera EPFL

Summary:

Important concepts and keywords to master

- **What senses are covered by the term somatosensory system?**
- **What are the 4 receptor types (Ia …) and what distinguishes them?**
- What is involved (anatomy, function) of the Myotatic reflex
- Afferent | Efferent | muscles spindles!
- Mechanoreceptors 🔥 How do they work?
- What relevant cell types are found in the 3 layers of skin?
- How do we study these systems – touch, proprioception?
- What was the Nobel Prize in 2021 awarded for?
- What is a somatotopic map? How detailed is it (limbs? Fingers?)
- How do you “map” the somatatopic map?!