Skin-related Sensory Processes

Electrosensation and mechanosensation

Topics we will be covering:

- General sensory system stuff
  - What is the general structure of a sensory cell
  - How do they fit into the bigger picture of the nervous system
- Skin sensory systems
  - Electrosensation
    - Passive and active
  - Mechanosensation
- How does the central nervous system process sensory inputs?

General features of sensory receptors

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- How are sensory cells structured?
- How do sensory cells fit into the bigger picture of the nervous system?

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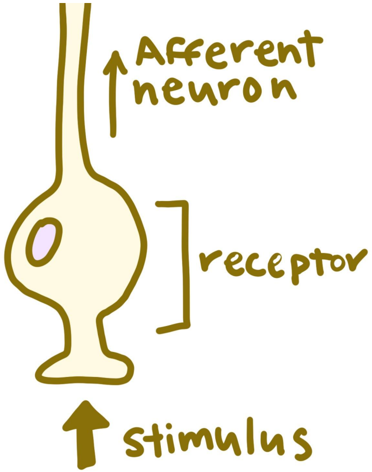

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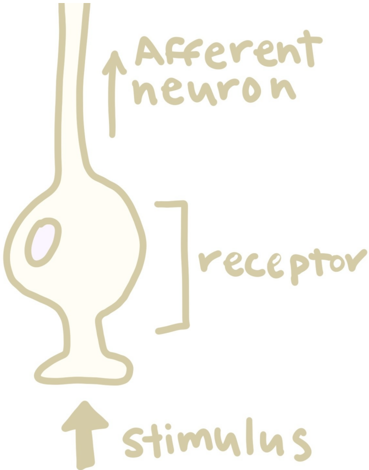
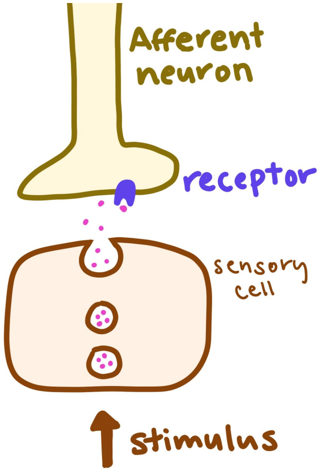
- There are two ways cells that receive sensory input can be structured:
    - The sensory cell itself can be a specialized **neuron** that sends an action potential to the central nervous system
    - Or it can be a **non-neuronal sensory cell** that connects to an afferent neuron that sends signals to the central nervous system





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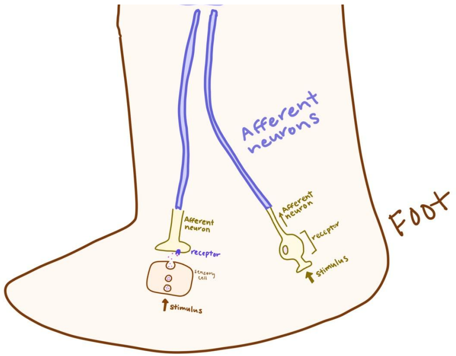

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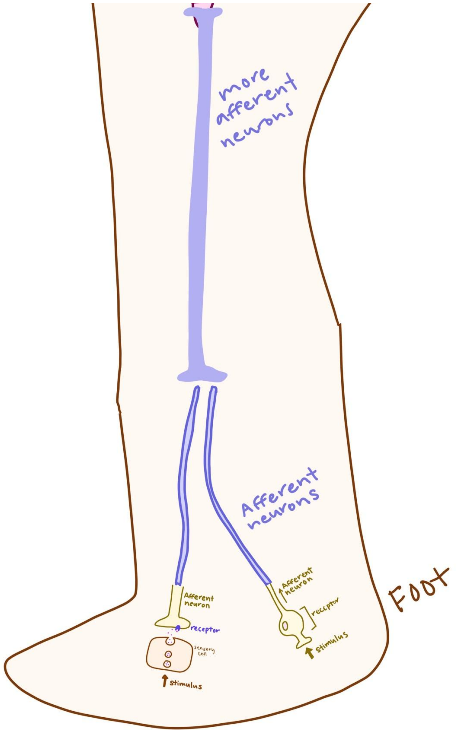

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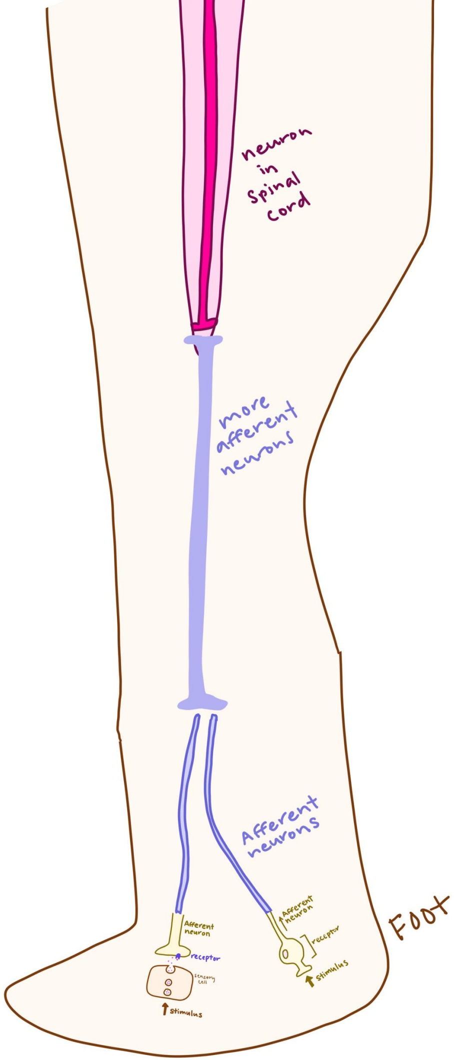
- Either way, the sensory cell must send signals:
  - Via the afferent neurons of the peripheral nervous system
  - Into the central nervous system (spine and brain) for **interpretation and processing**



Interpretation and Processing of Sensory Inputs

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- How do sensory cells respond to prolonged stimuli?
- How do sensory cells respond to stimuli of different intensities?
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Again, I'm going in a slightly different order than the lecture did, which I think will make much more sense.

Good resource:

http://droualb.faculty.mjc.edu/Course%20Materials/Physiology%20101/Chapter%20Notes/Fall%202007/chapter_10%20Fall%202007.htm

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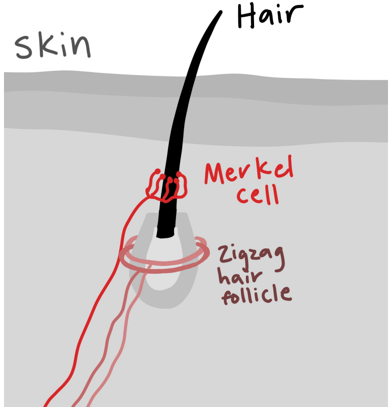

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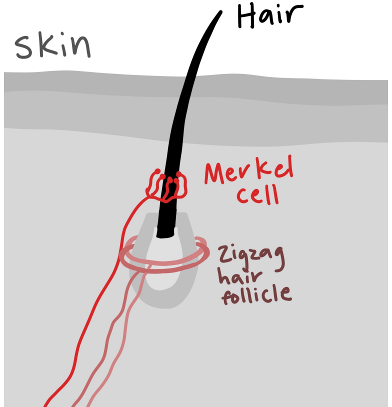

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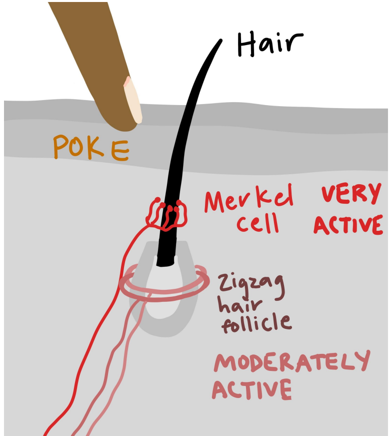

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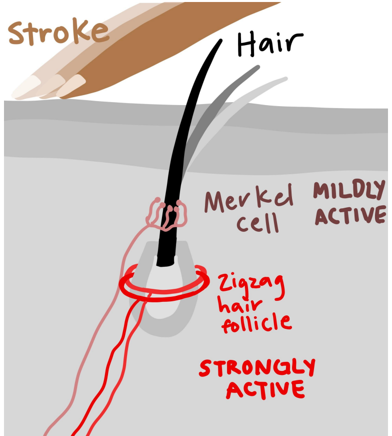

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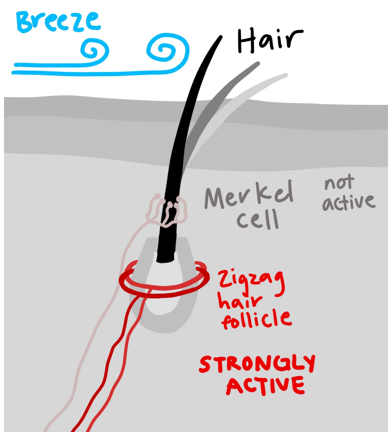

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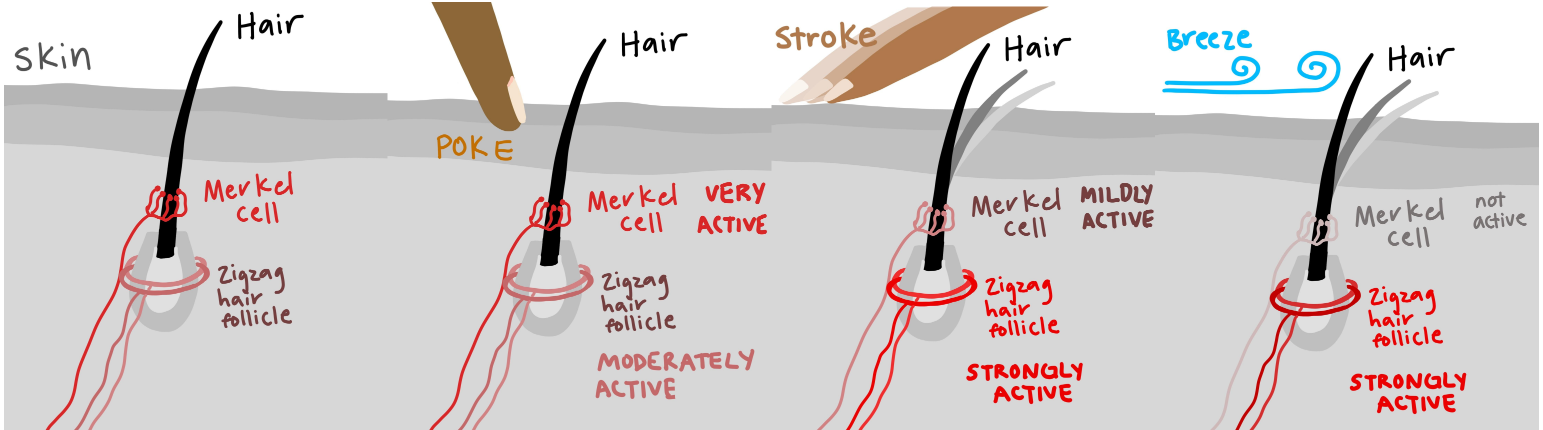
  - **Different combinations create different sensations.**



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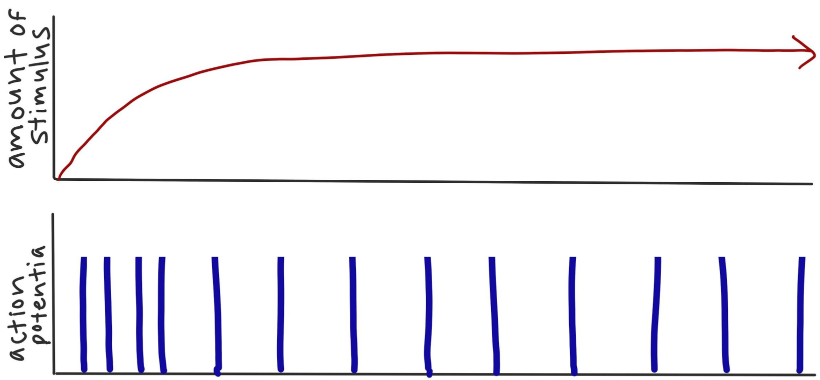

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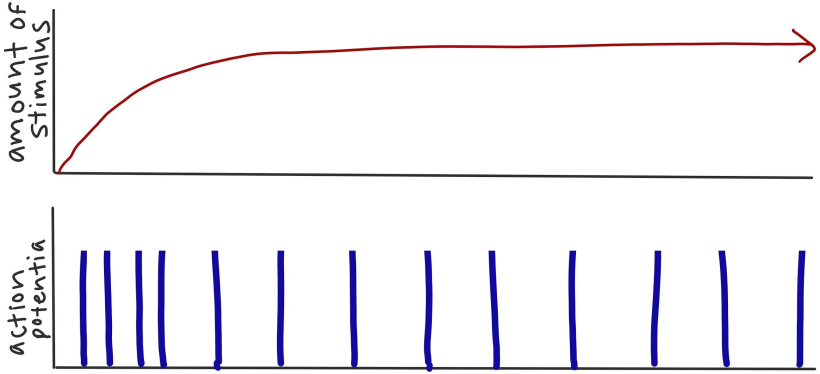
     a. Ex: pain receptors.



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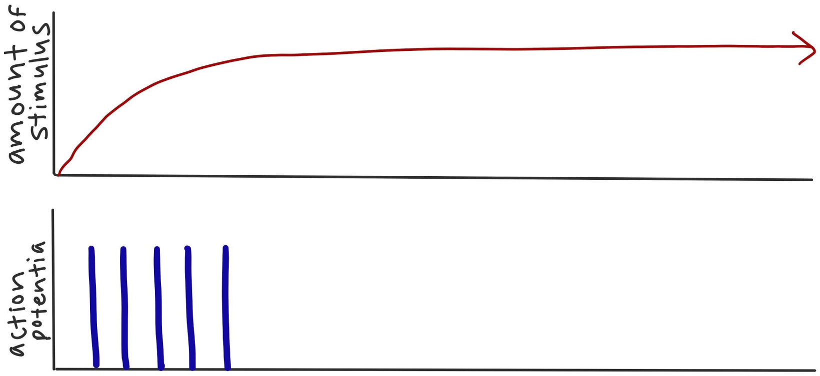

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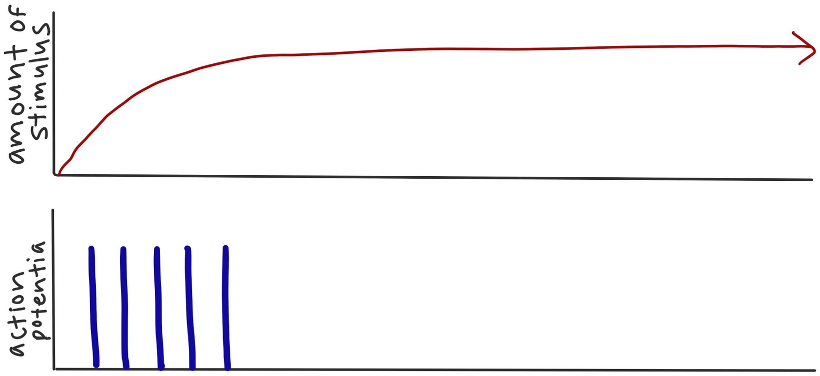

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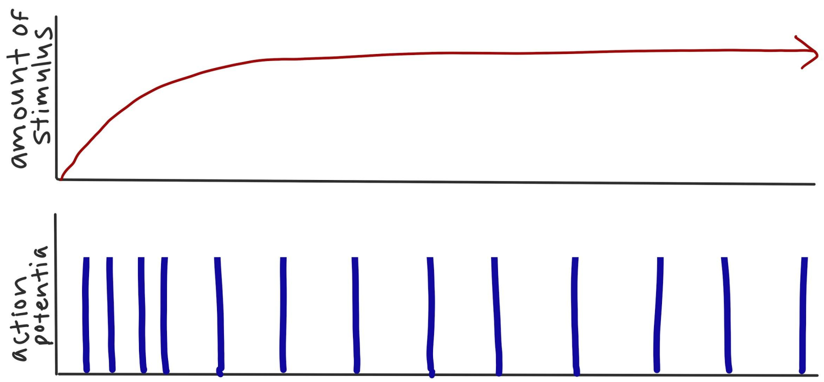
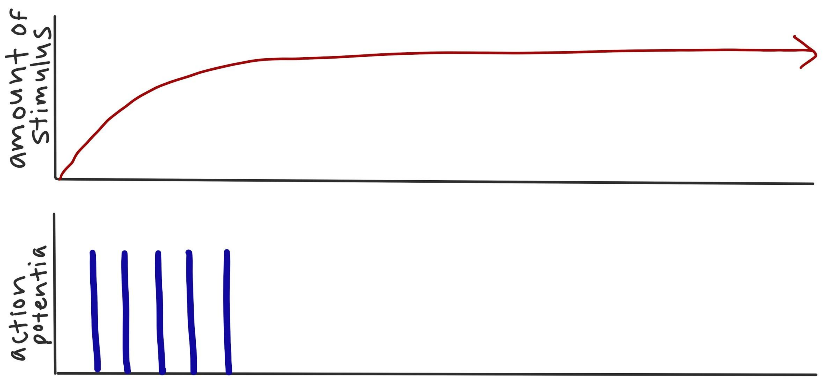
- You should understand these two types of response
- You should know, for each mechanoreceptor we will cover, whether it is tonic or phasic.





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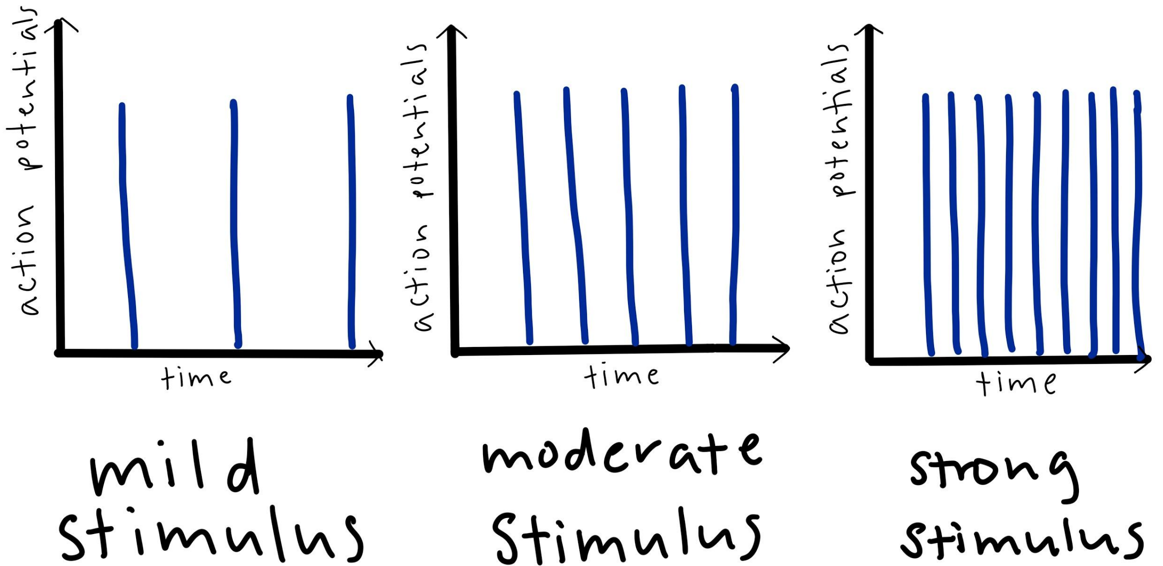

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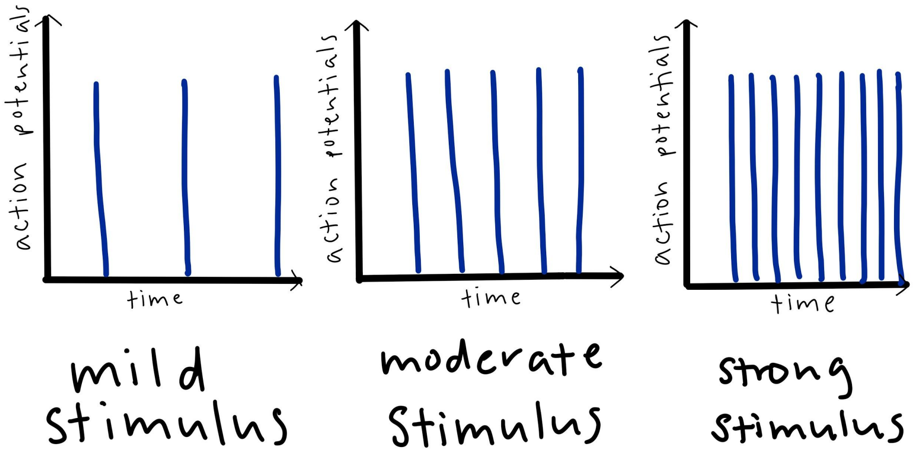

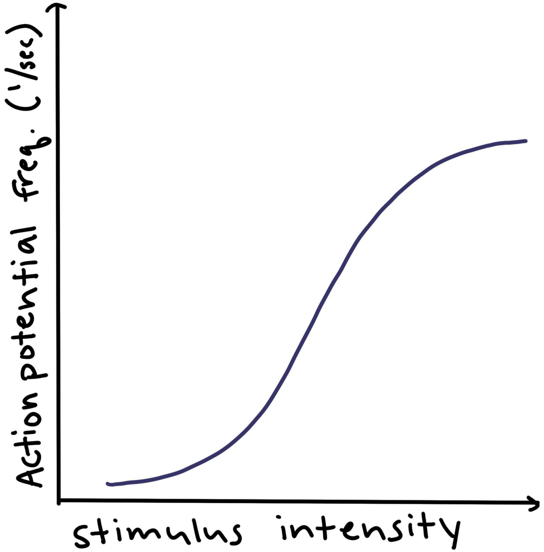

Frequency coding

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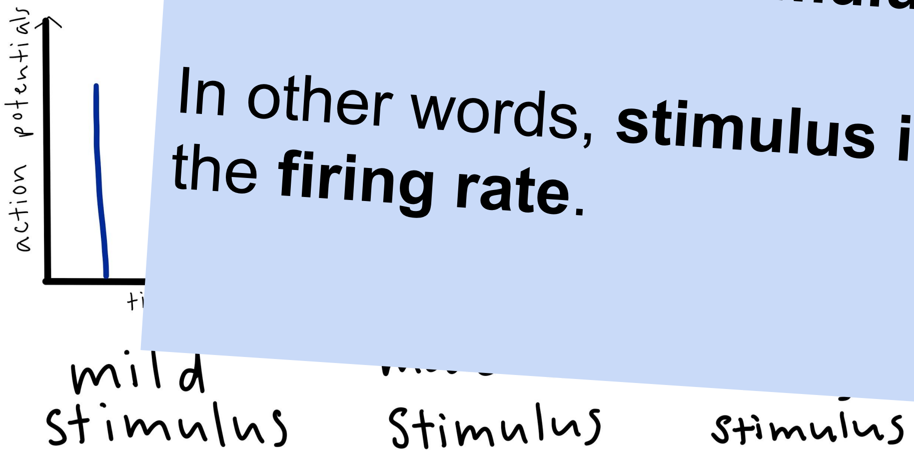
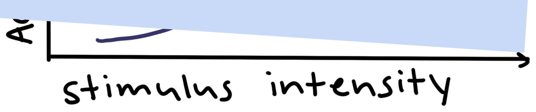
- You … hard
  - …
- Th… g.
- As… s.

Take-home message:

The action potential **firing rate** is what encodes information about **stimulus intensity**.

In other words, **stimulus intensity** is encoded in the **firing rate**.





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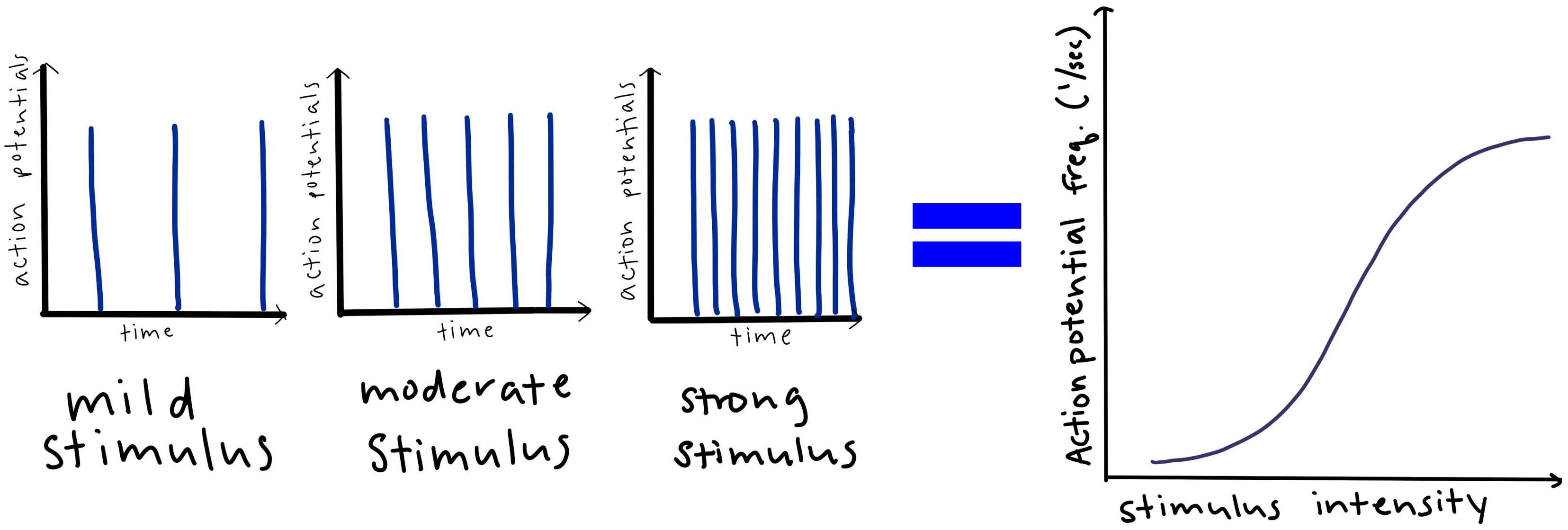

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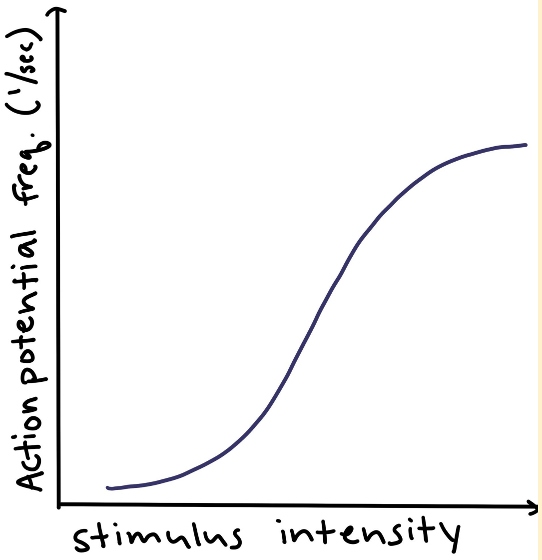

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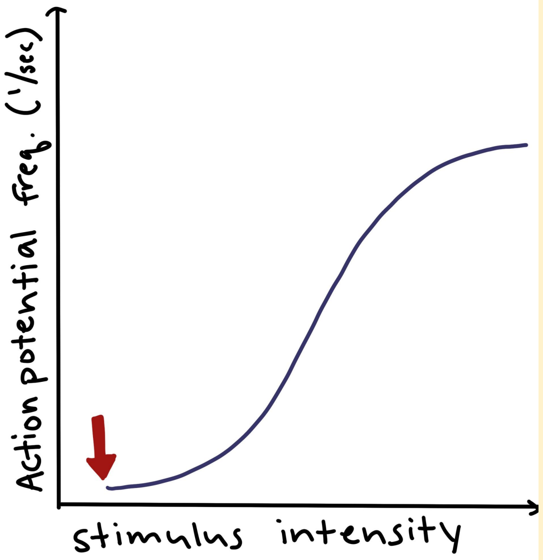

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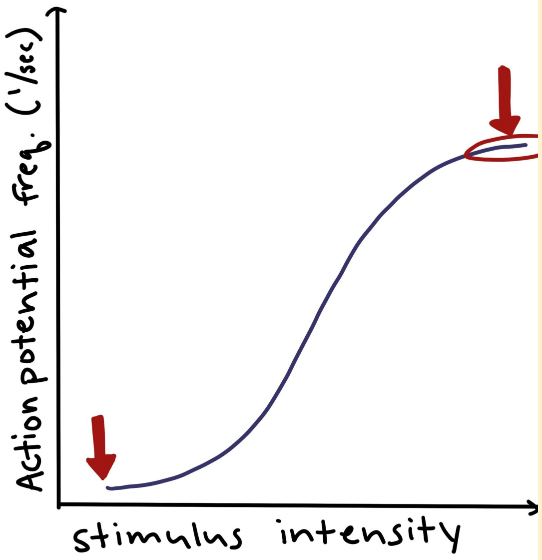

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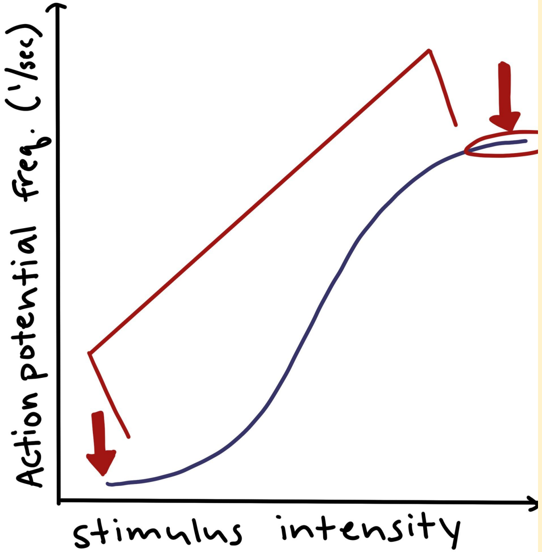

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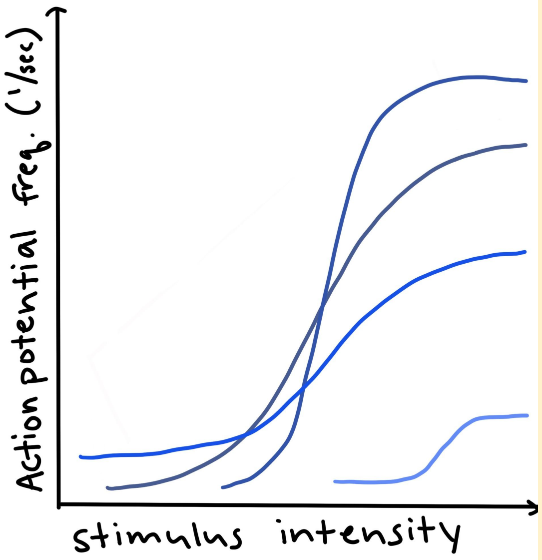

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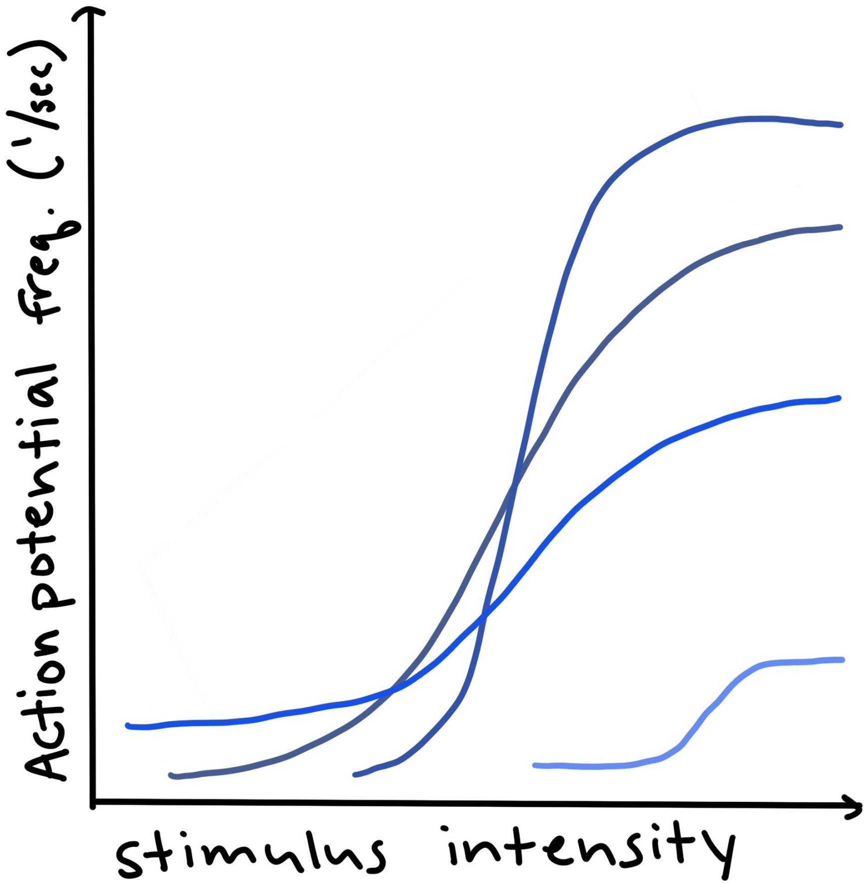

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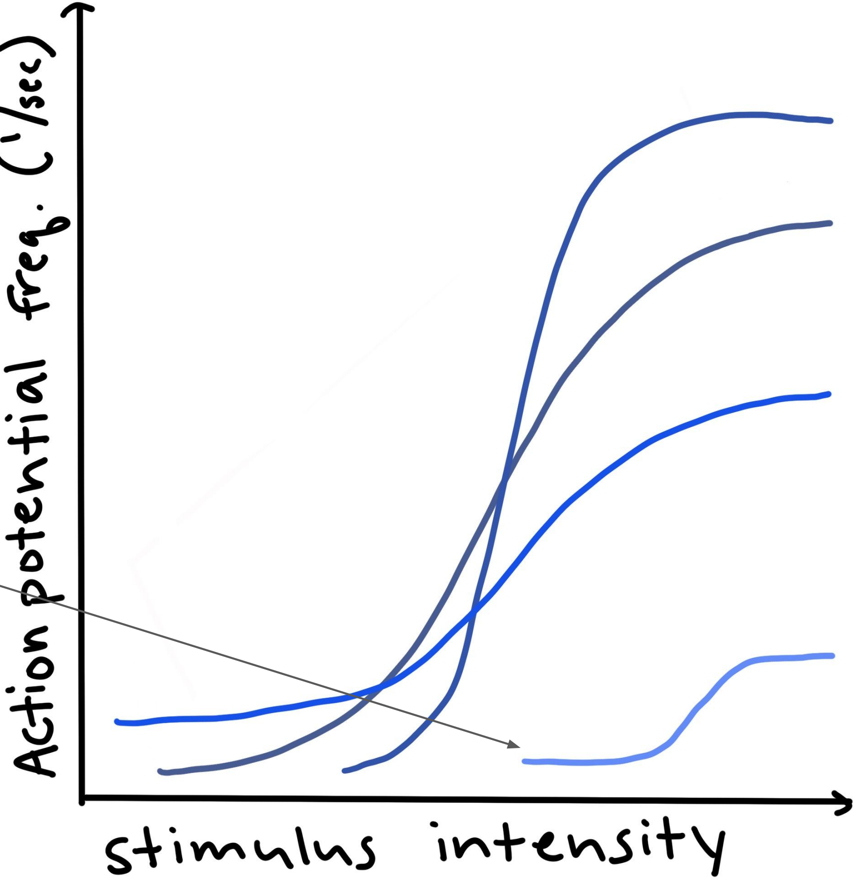

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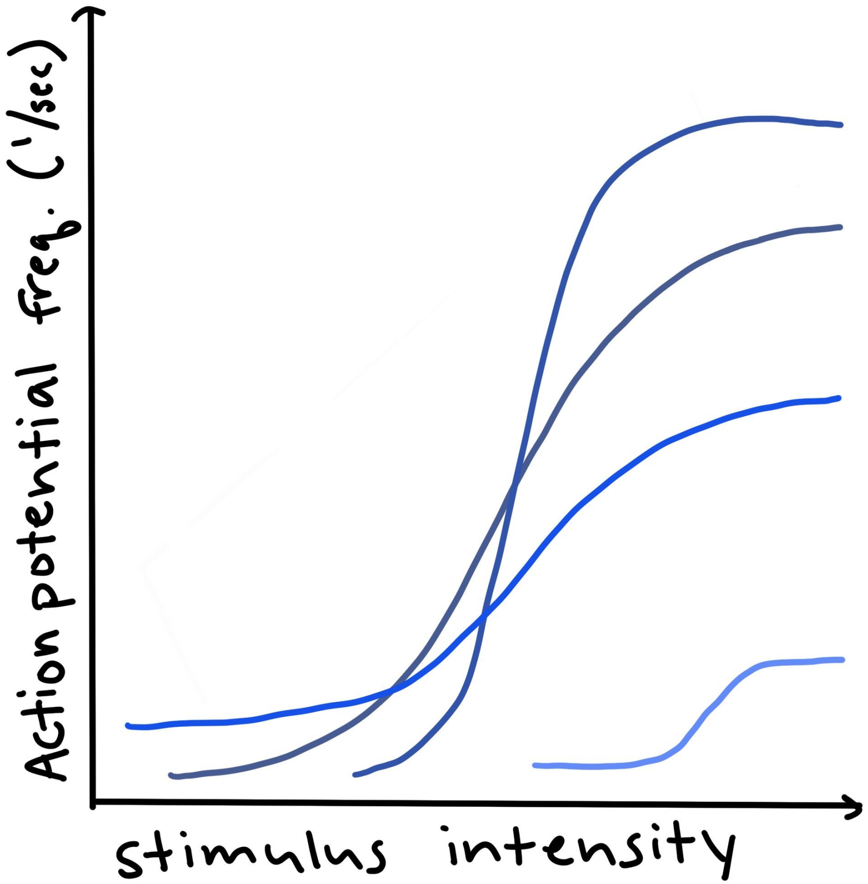

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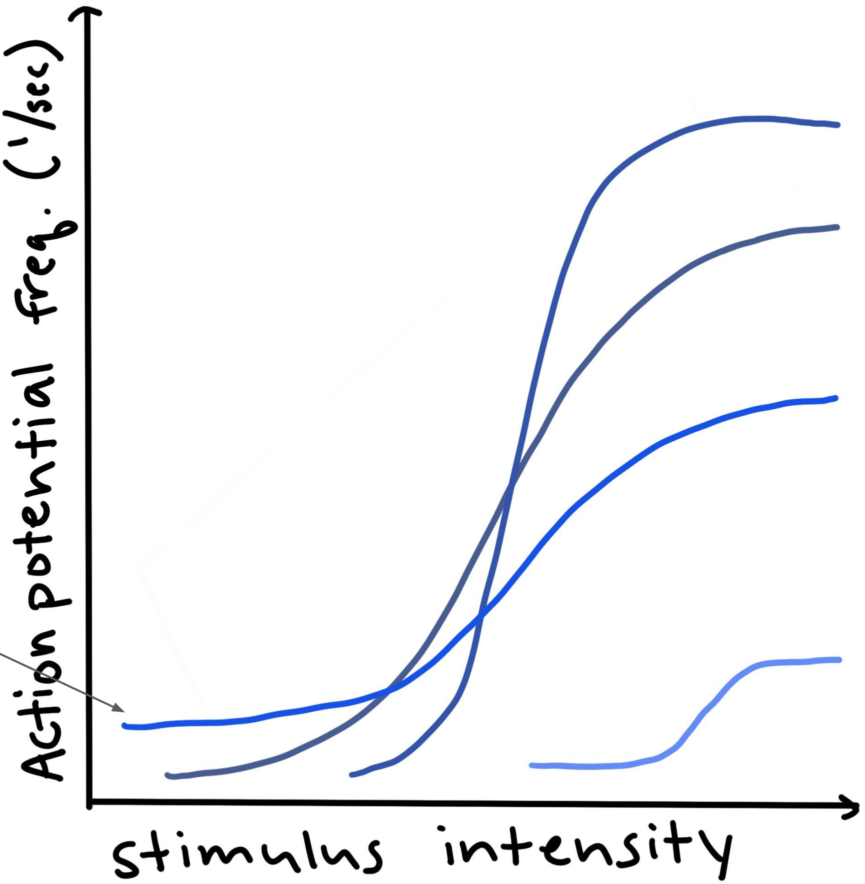

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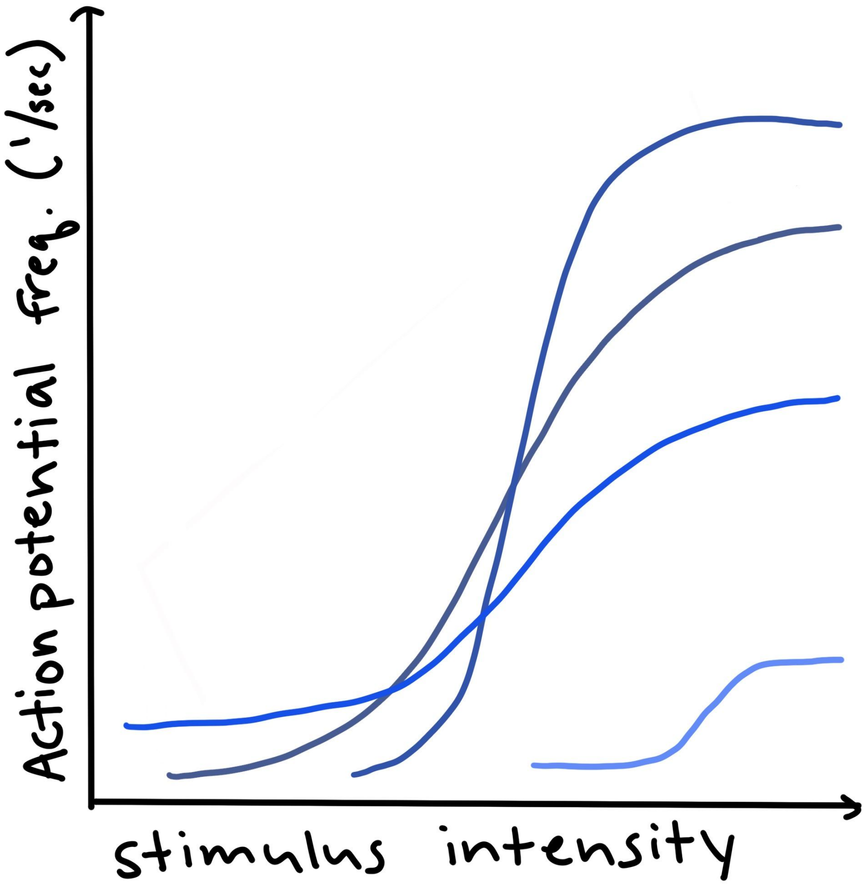

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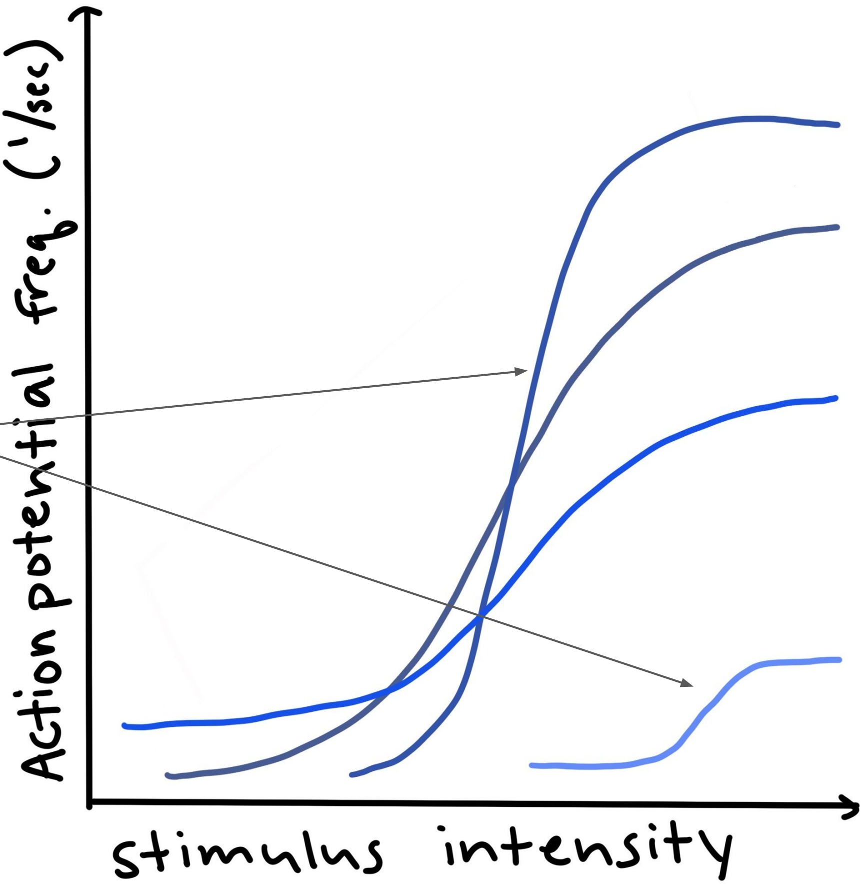

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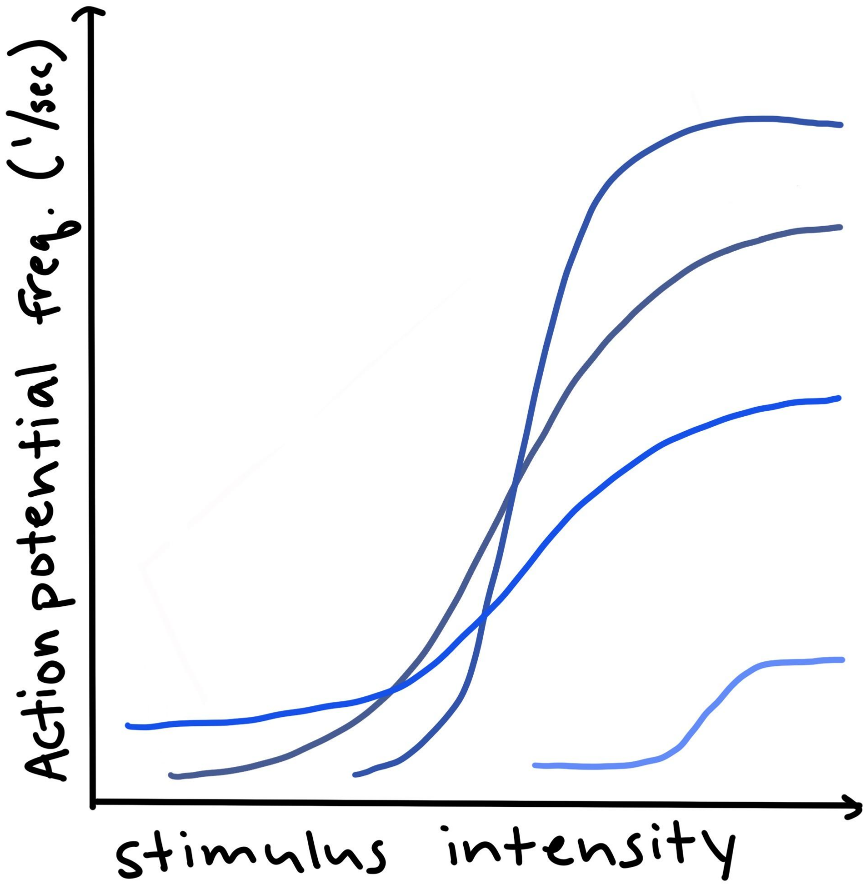

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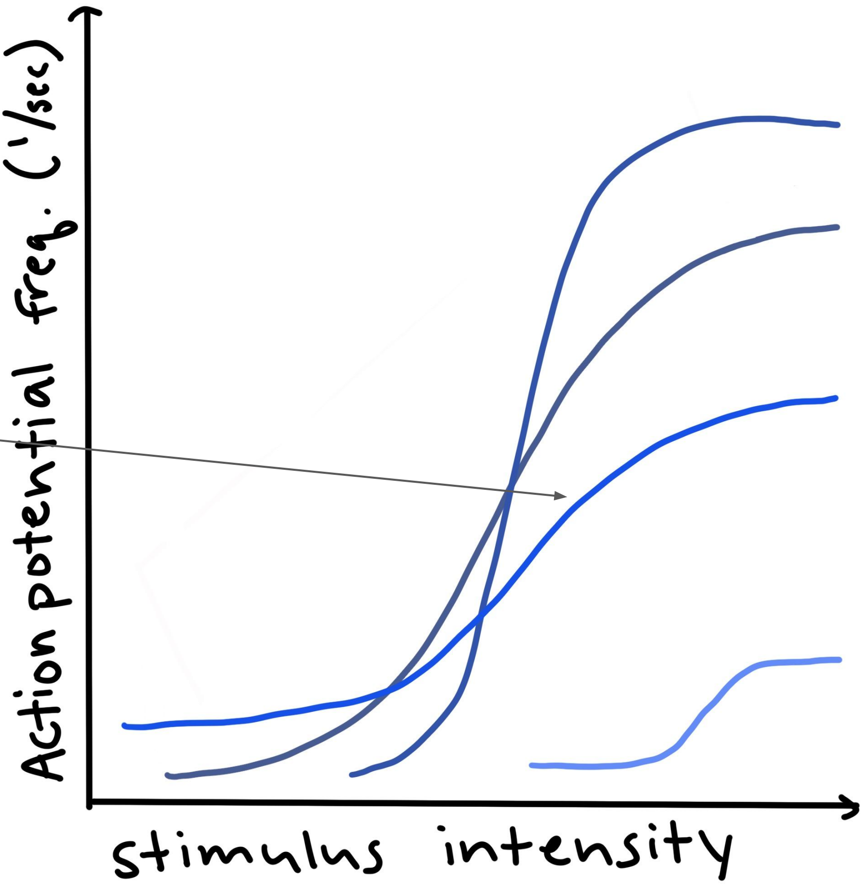
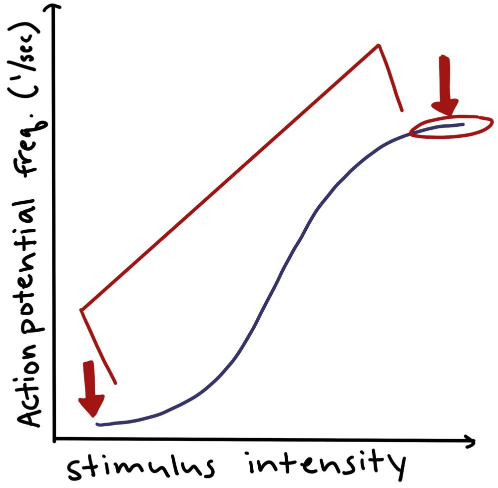
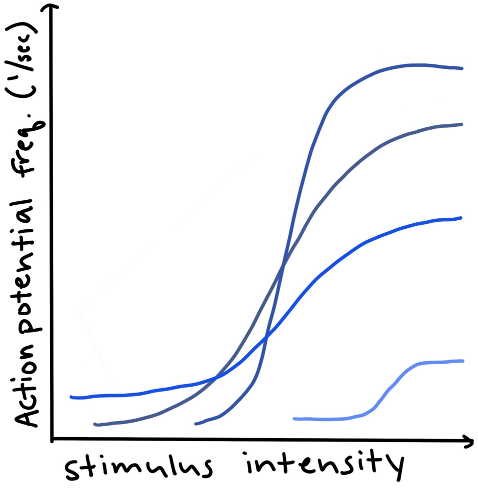


Frequency coding

Intensity sensing: take-aways

- You should understand what **frequency coding** means
- You should understand the **three features of a frequency coding graph**
- You should know that **different receptors have different threshold and dynamic ranges**, and what that means about their **sensitivity**.





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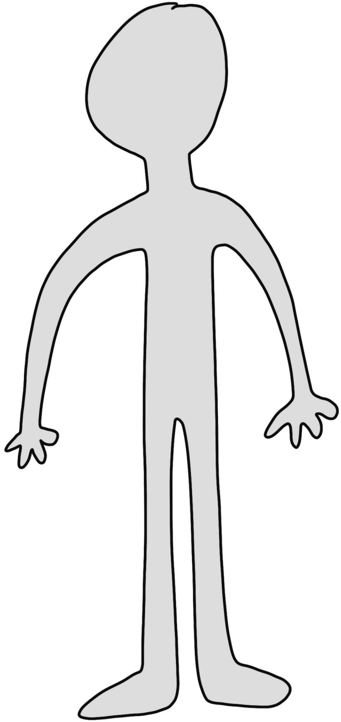

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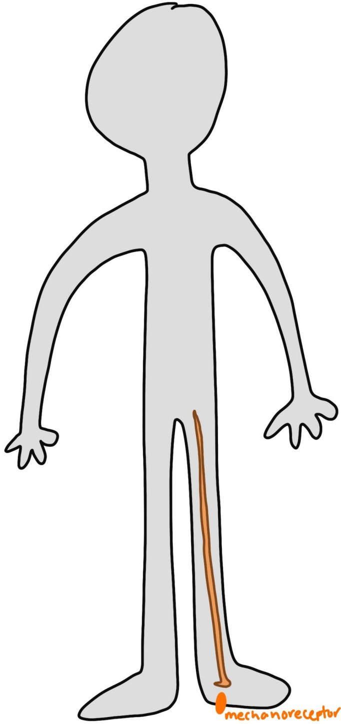

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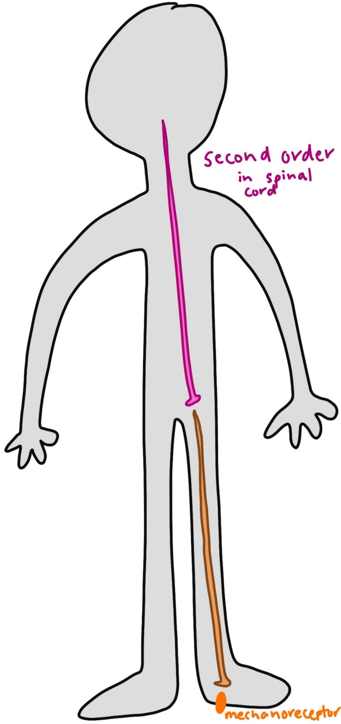

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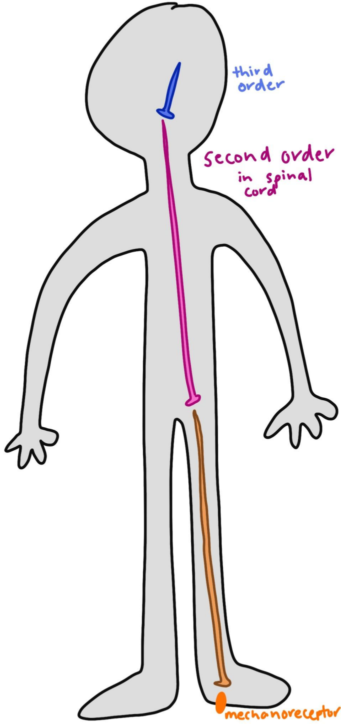

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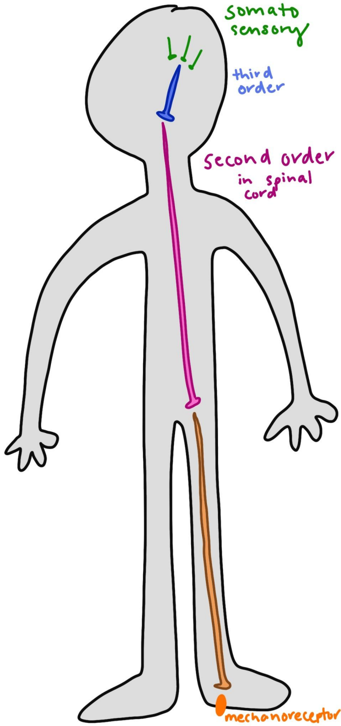

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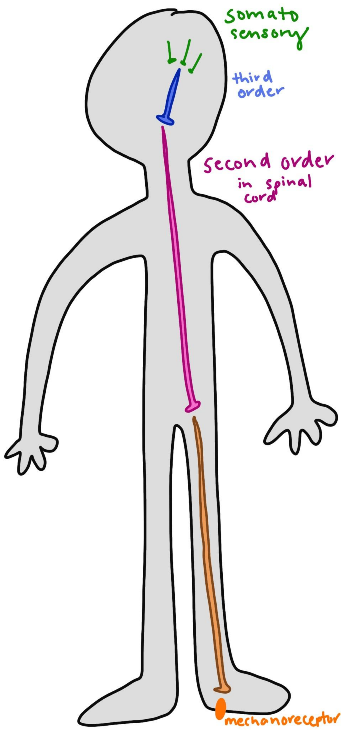

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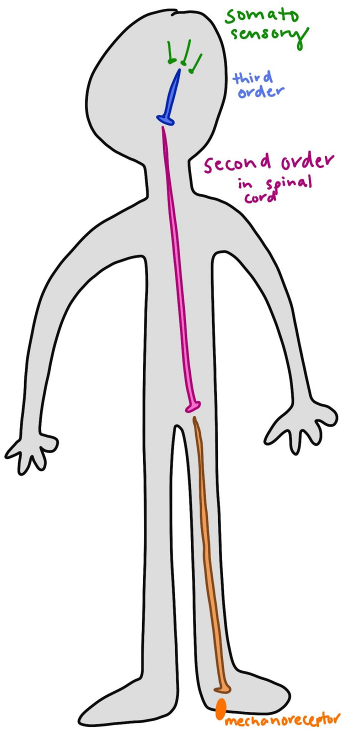

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This allows the somatosensory cortex to use **receptor type, location, phasic/tonic properties, receptive field overlaps, conduction velocity** and other events happening nearby over time to make **specific interpretations** about the type of stimulus.

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- Lots of signals are **ignored** by the somatosensory cortex so that only critical stimuli get attention.

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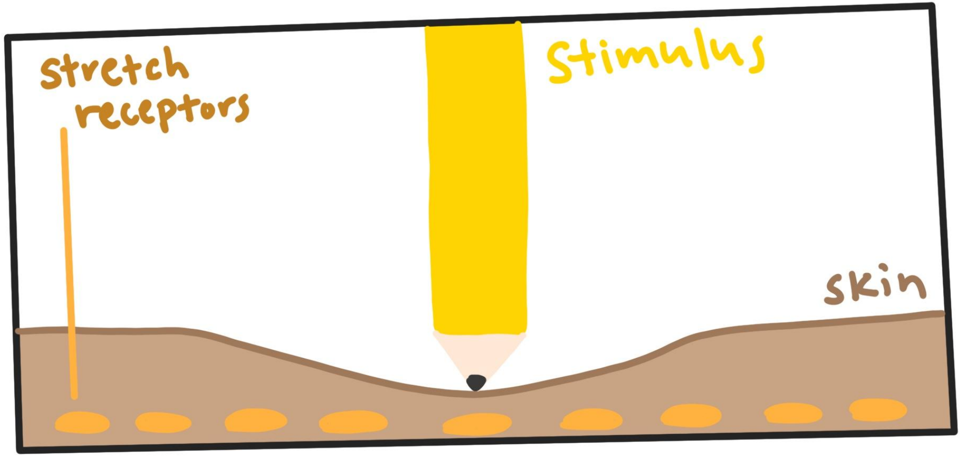

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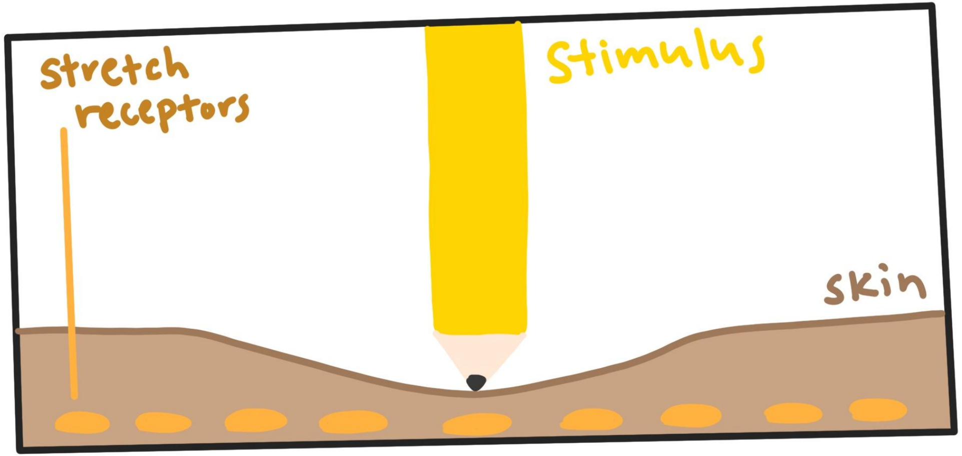

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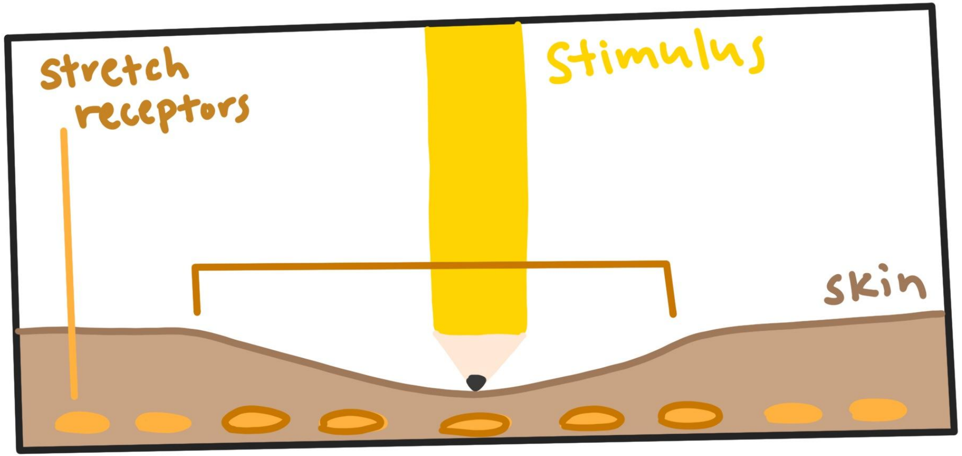

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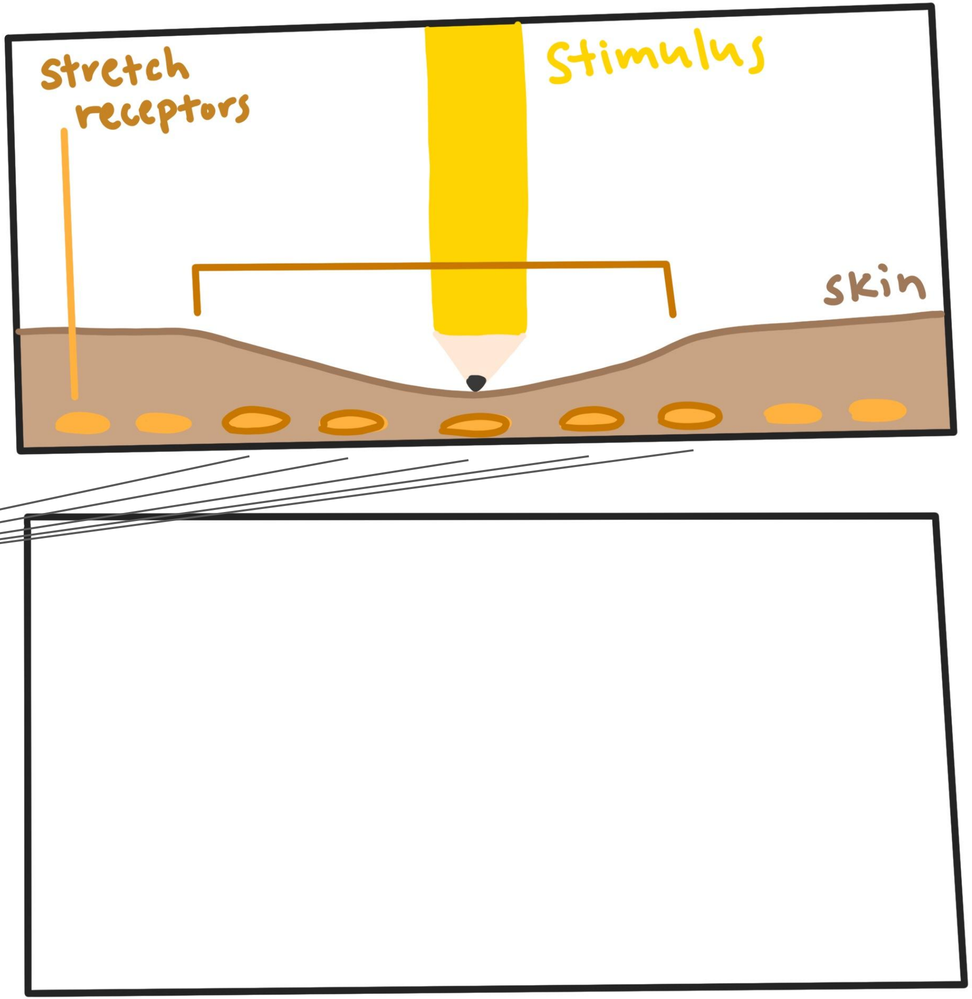

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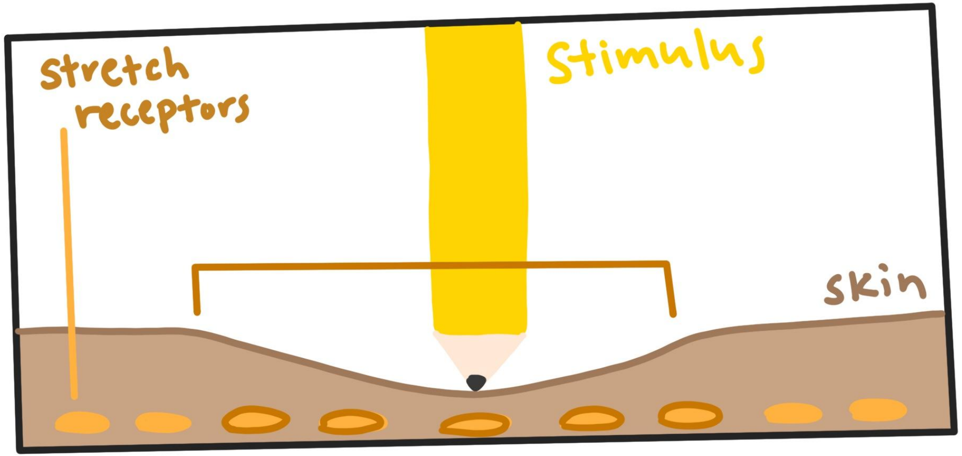

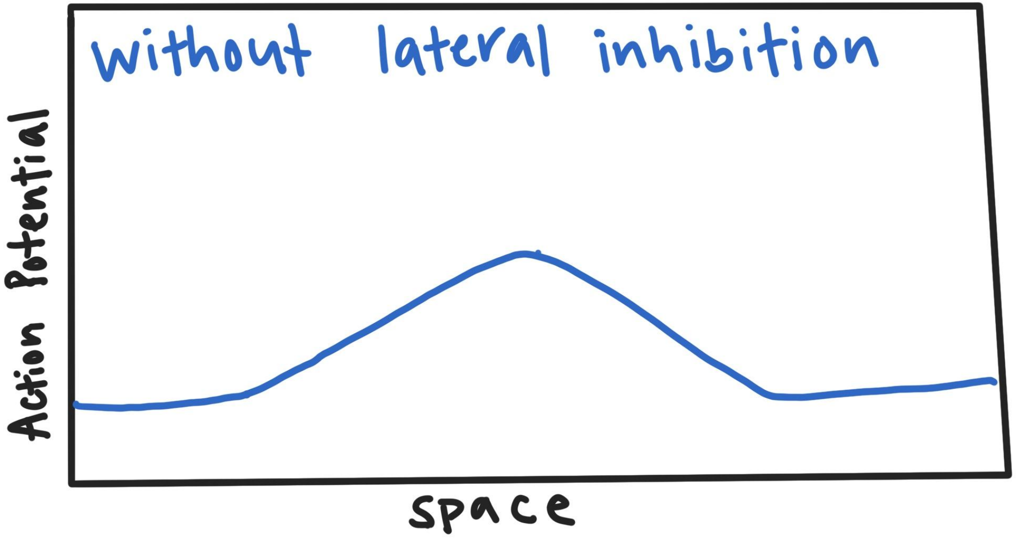

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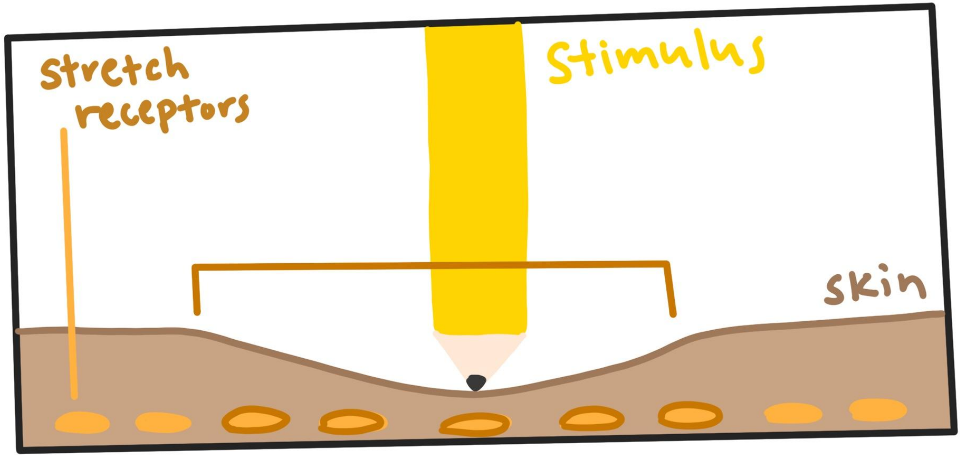

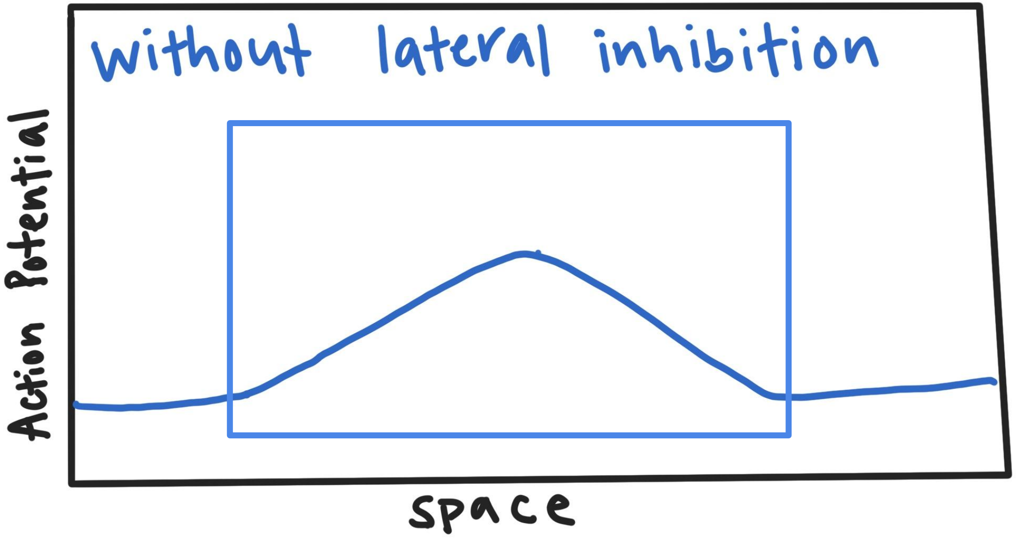

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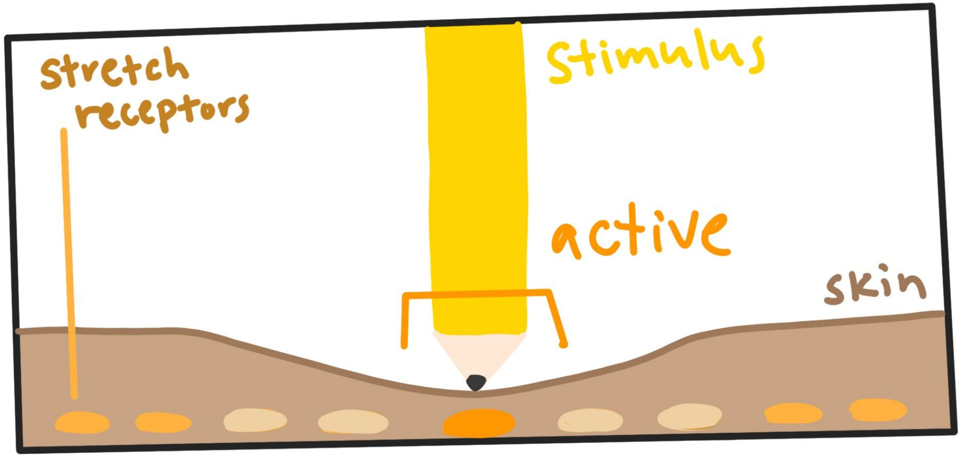

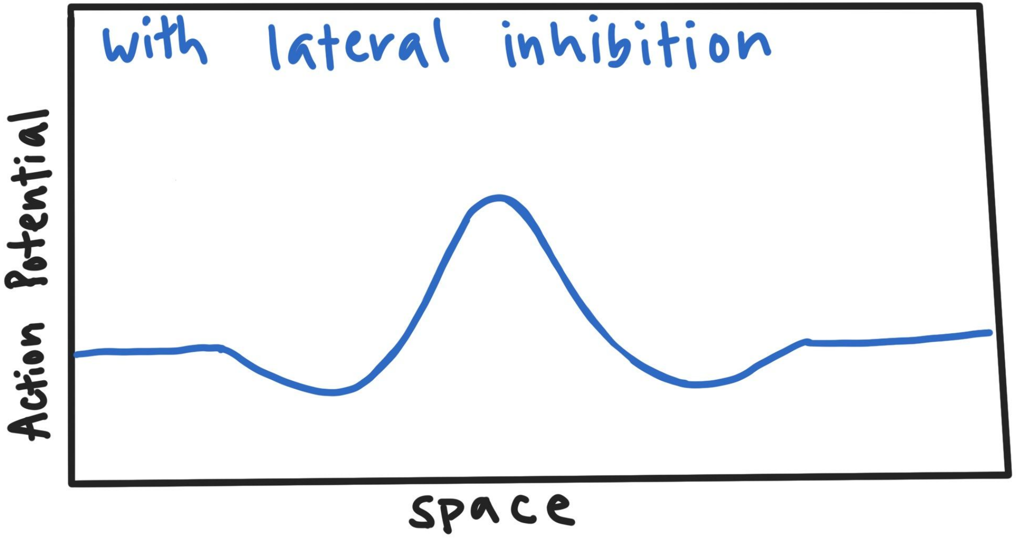

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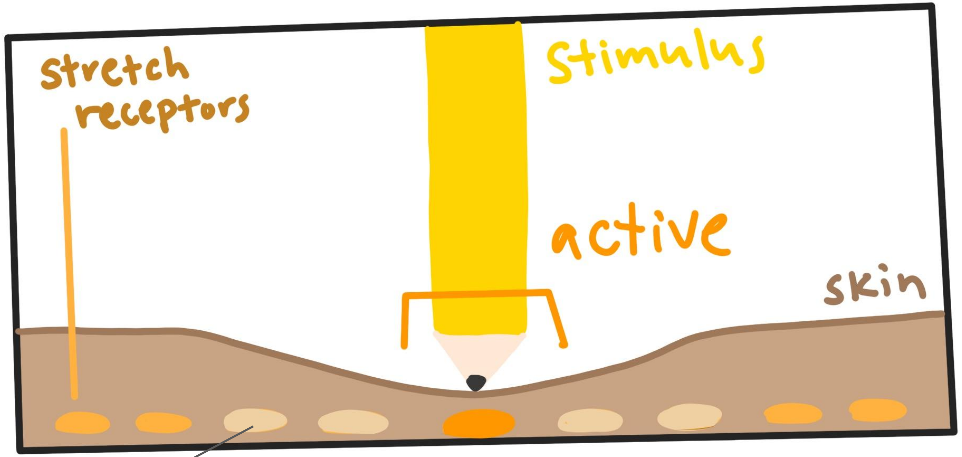

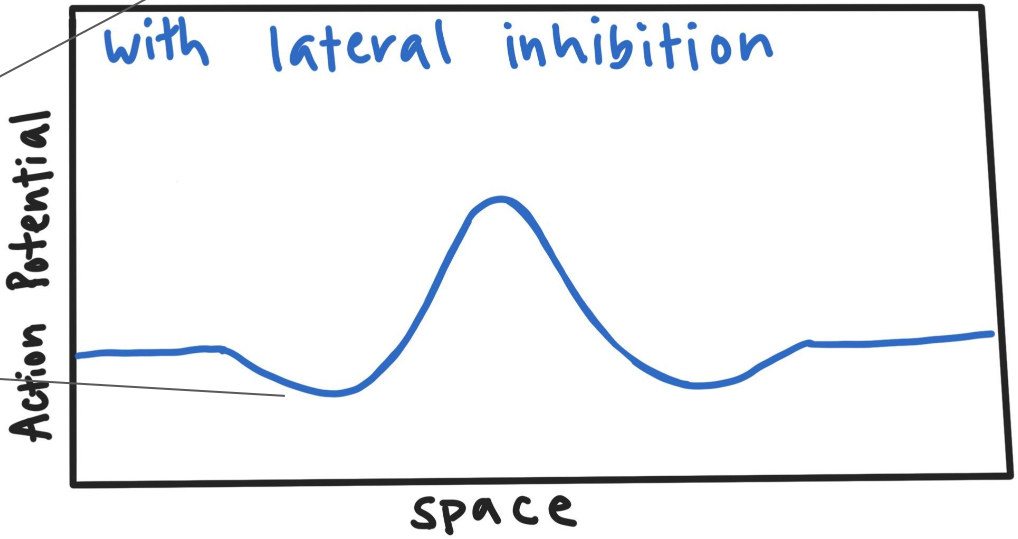

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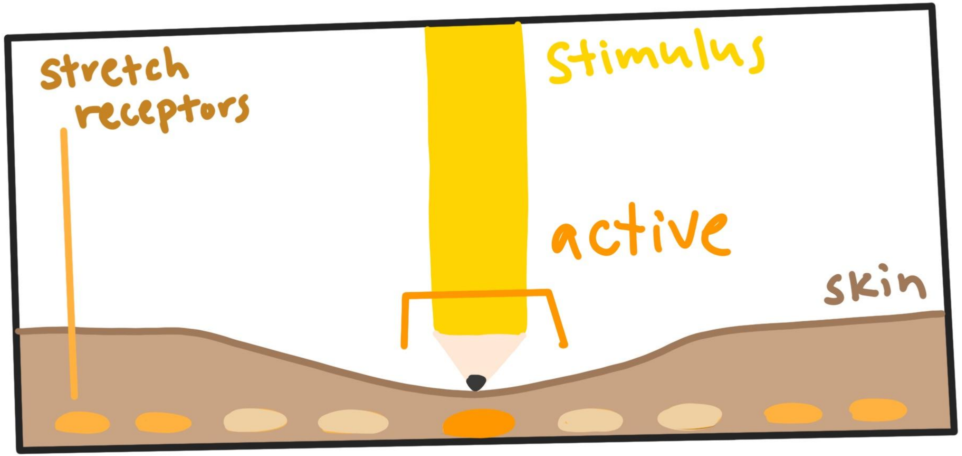

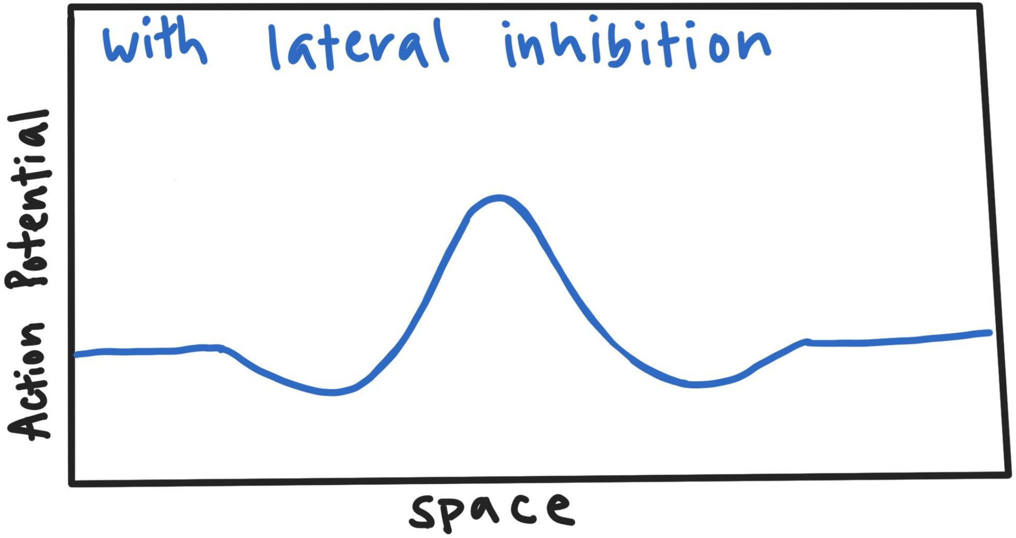

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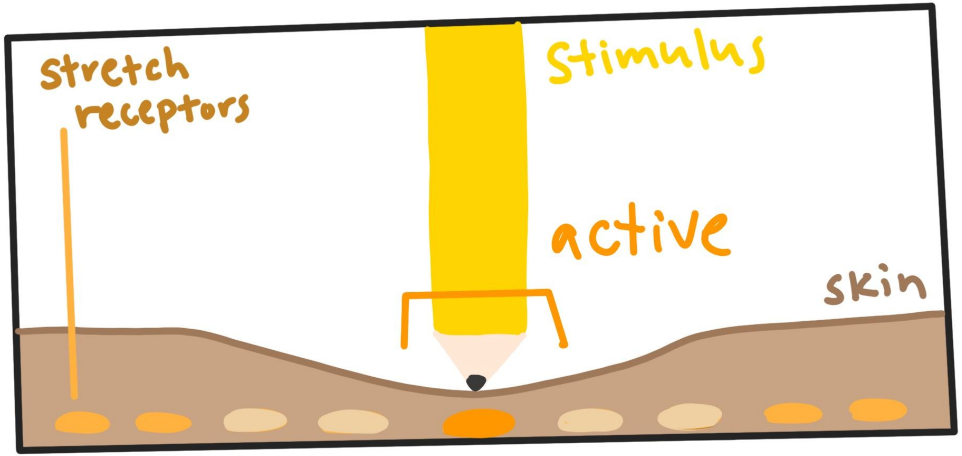

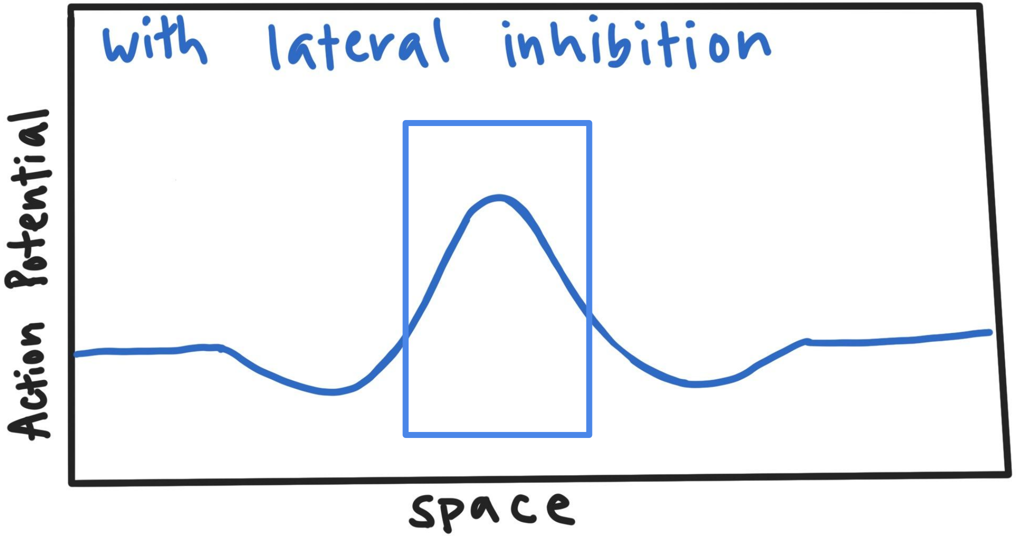

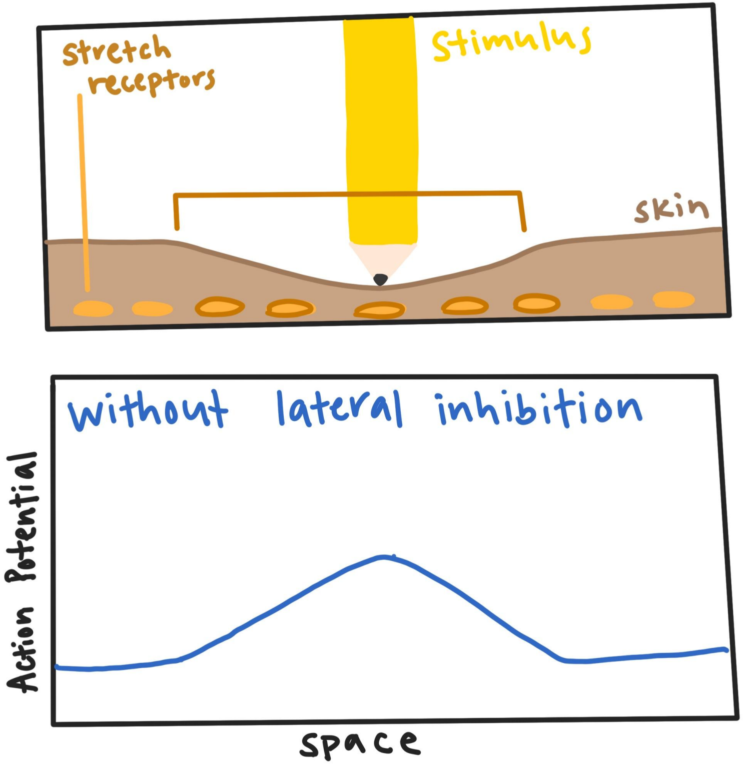
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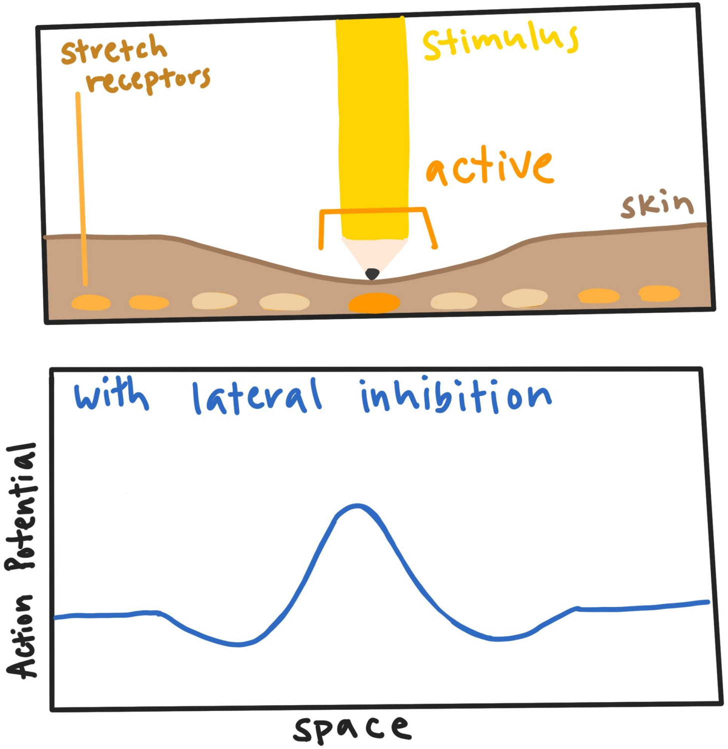
skin
without lateral inhibition
Action Potential
space

vs.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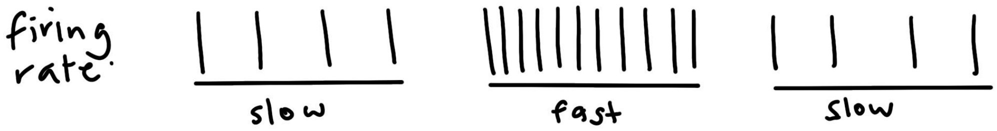

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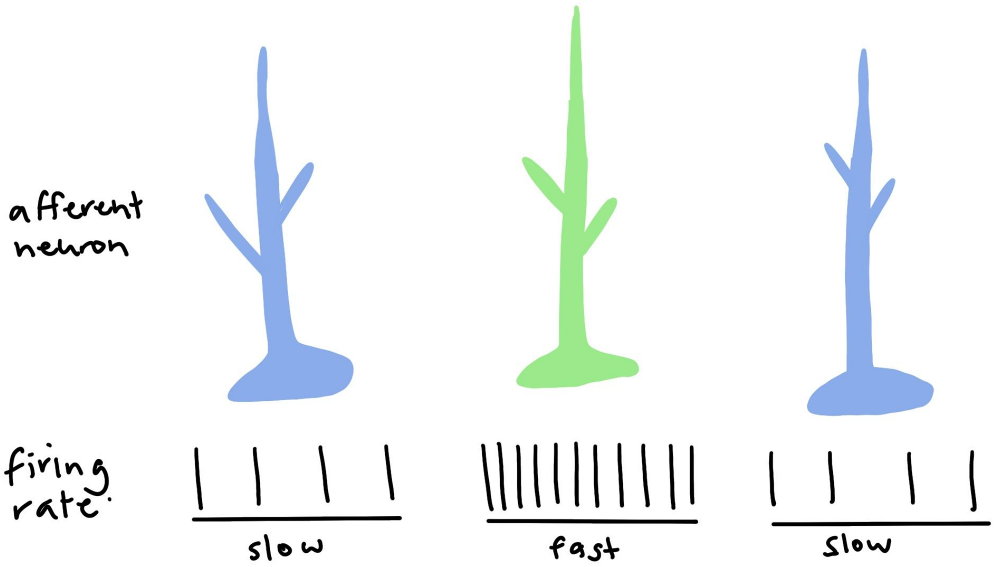

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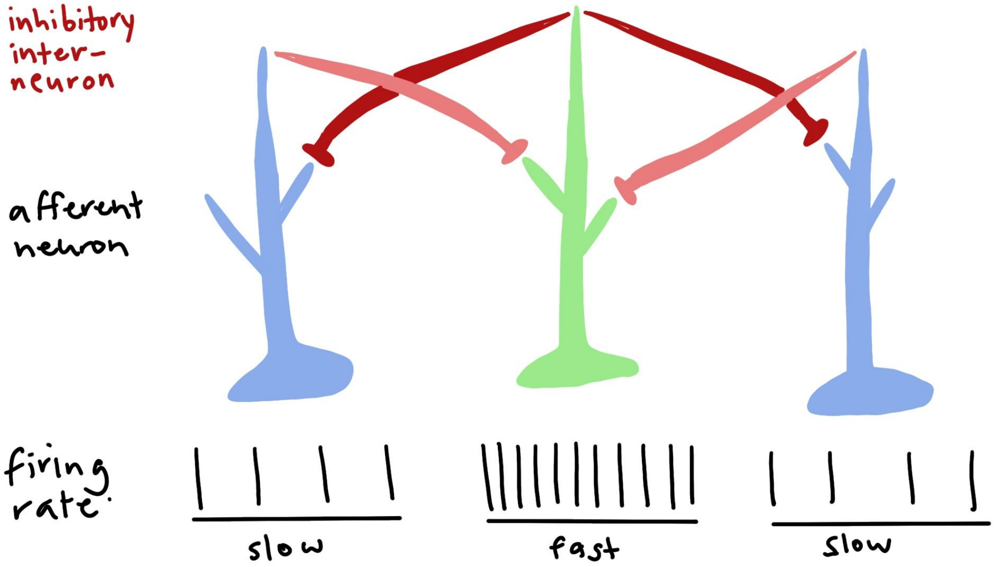

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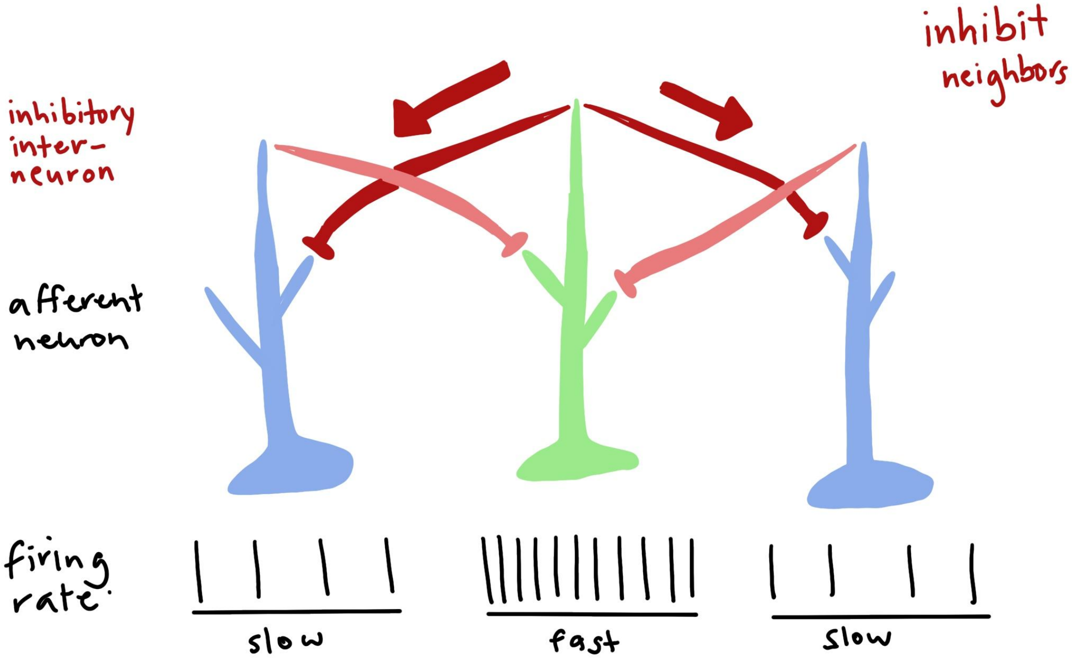

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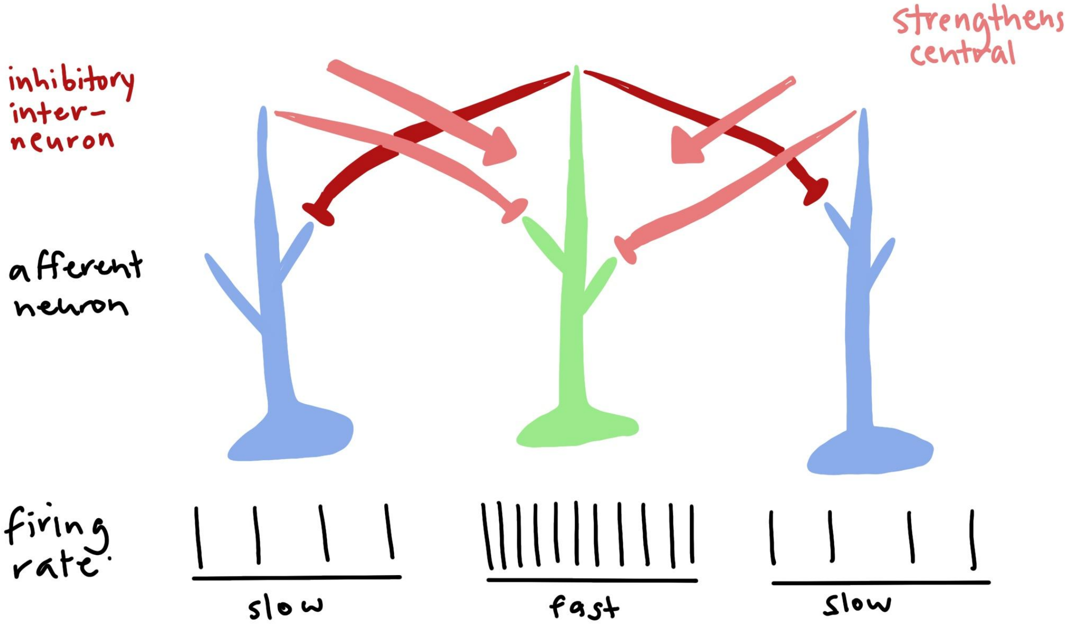

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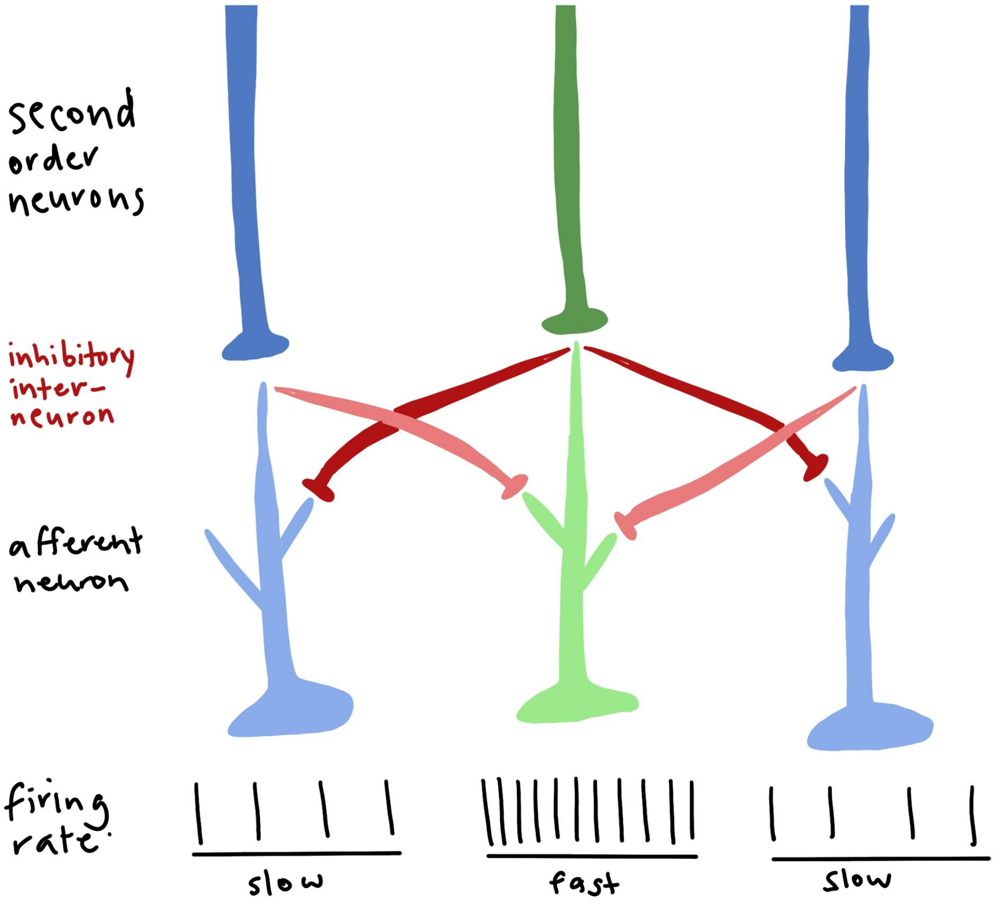

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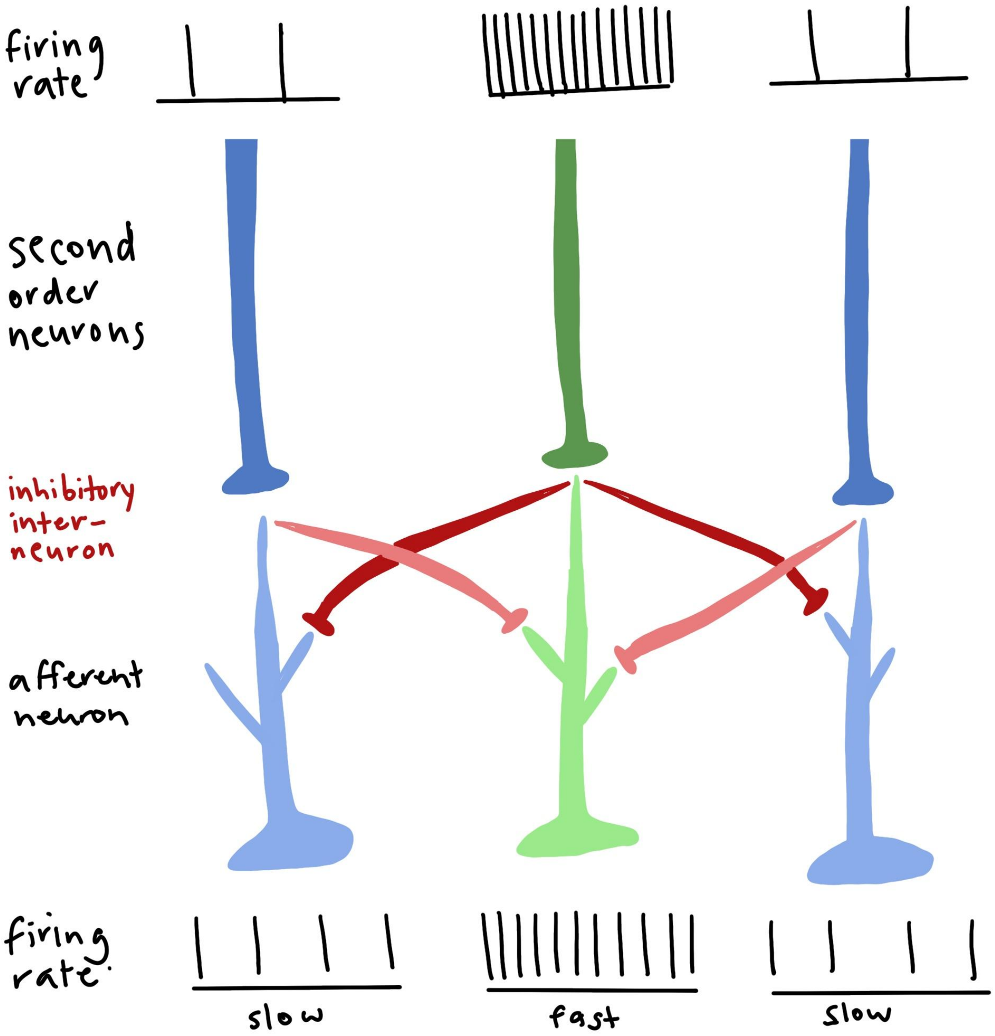

Lateral inhibition: takeaways

- How does position within a receptive field affect action potential frequency/ spike rate?	More central = more frequent
- What is lateral inhibition?	
- Why is it important?	Allows fine spatial discrimination
- Physiologically, how does it happen?	Excited neuron inhibits neighbors
- Does it only involve first order processing?	No, second order interneurons too.

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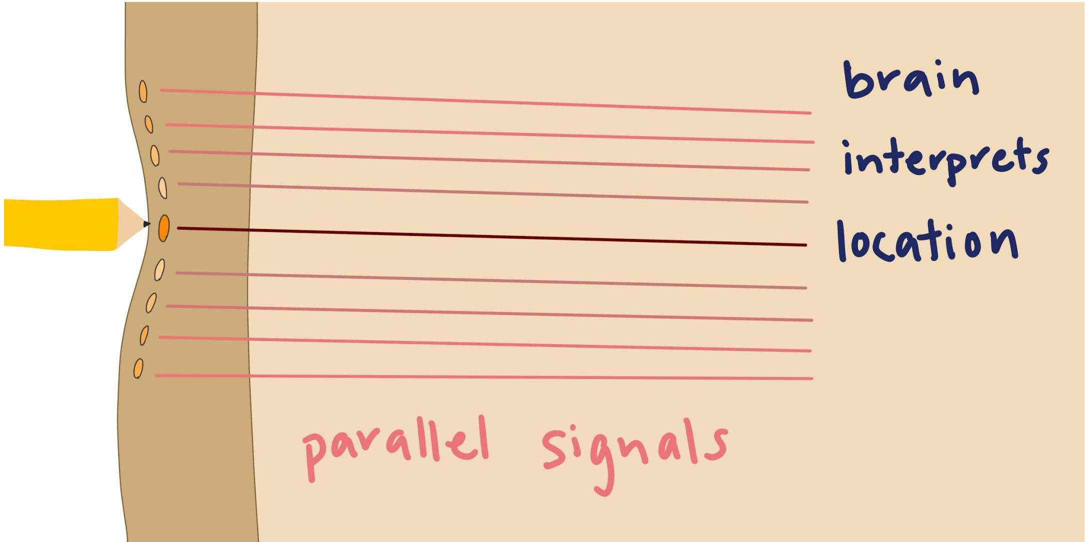

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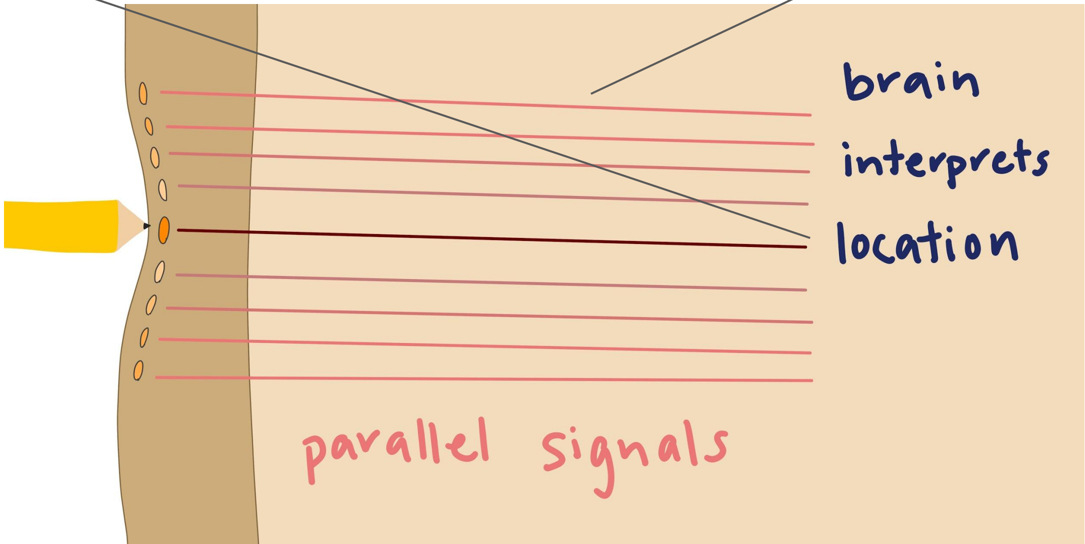


From Dr. Selvaraj:

“Frequency coding, population coding and lateral inhibition are core concepts to be understood for solving problems.

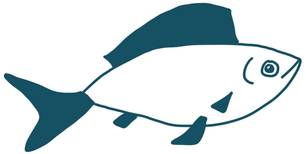
For the CNS circuits, they should know that there are 3 orders of transmission and that it is channeled through the thalamus to the cortex, the 4th order being processing within the cortex.”

Electrosensation

Electrosensation

- How can organisms sense electricity?
- What is the difference between active and passive electrosensation?

Why would organisms need to sense electricity?



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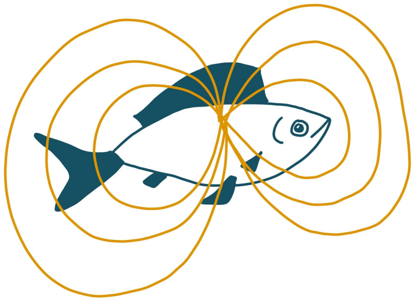

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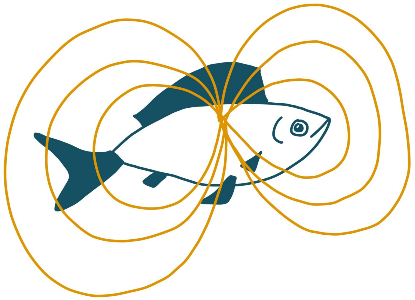

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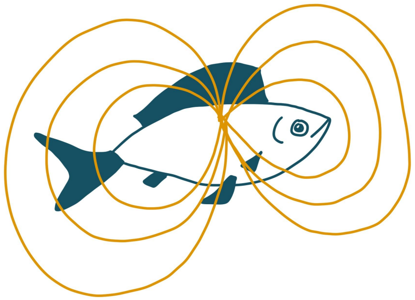
- Some organisms also communicate via electrical signals.



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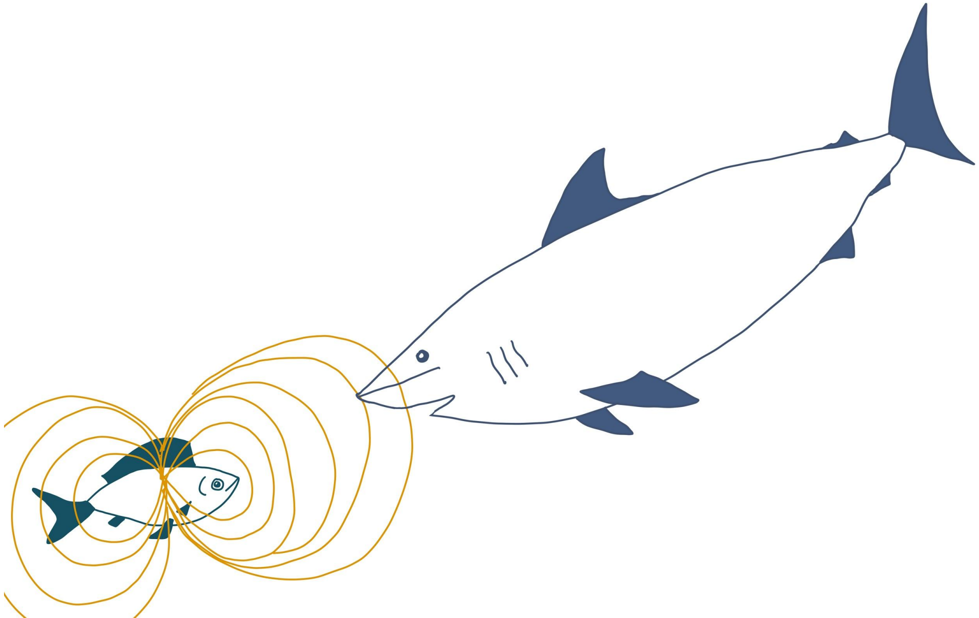

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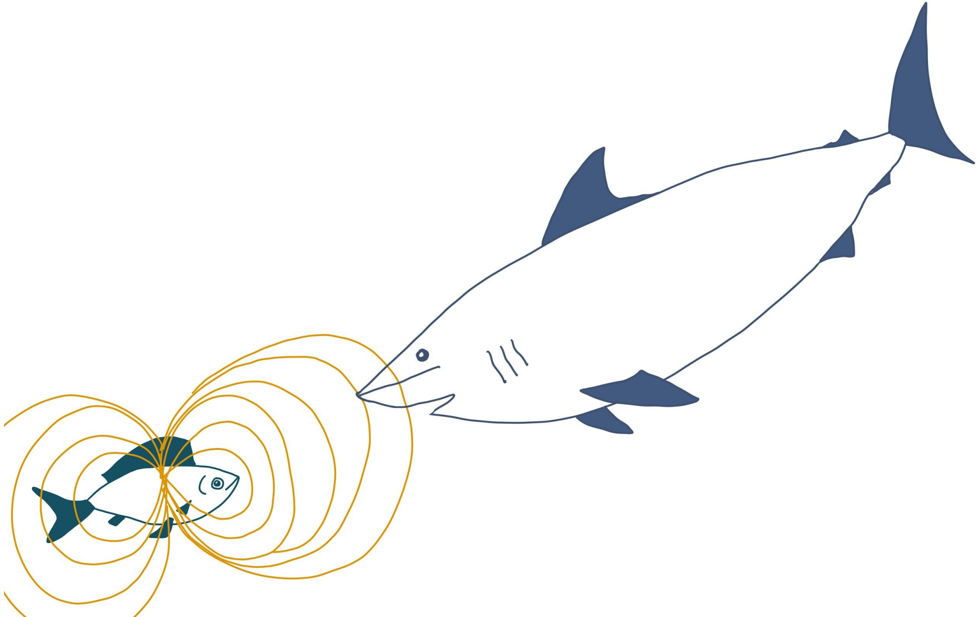

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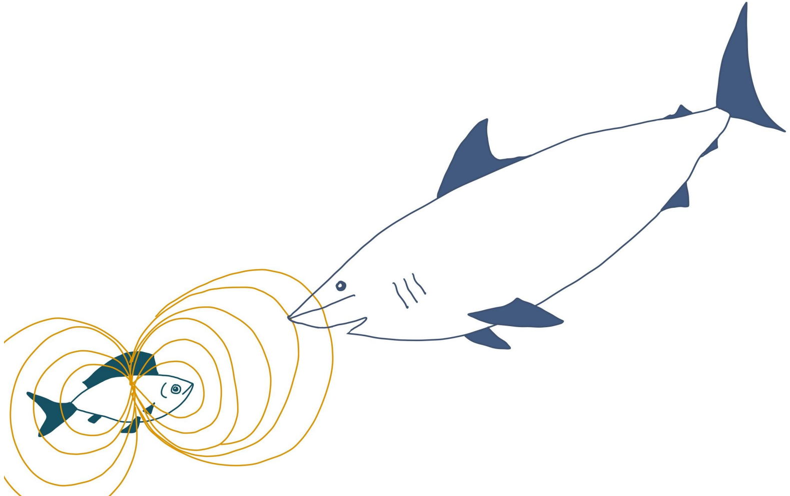

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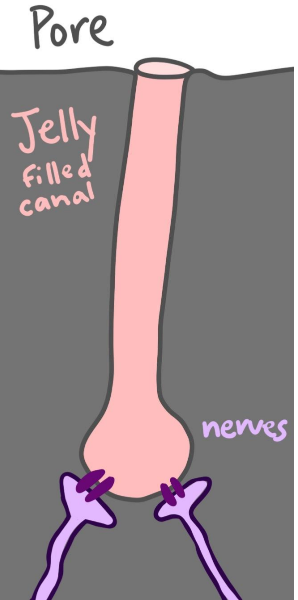

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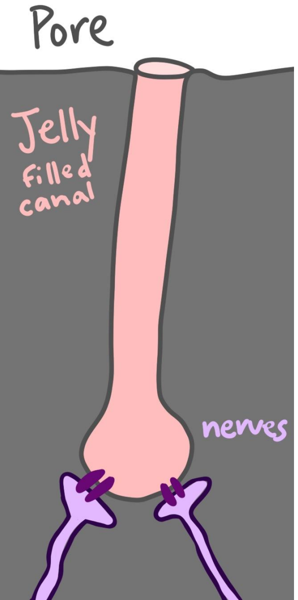

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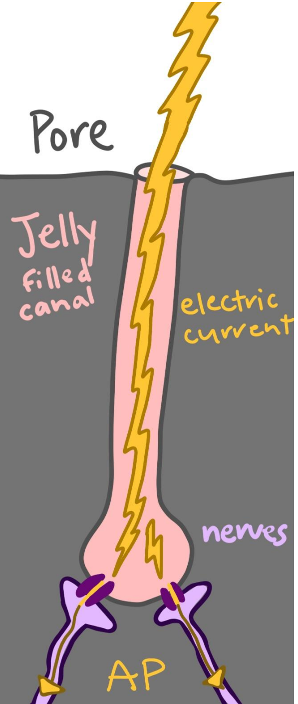

The lightning bolt is an artist's interpretation- this is NOT how a physicist would depict this!

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Sharks rely on this sensory system so much that they will preferentially attack electric diodes over dead, chopped up fish!

(slide 8 of lecture 20)

… **keratan sulfate**

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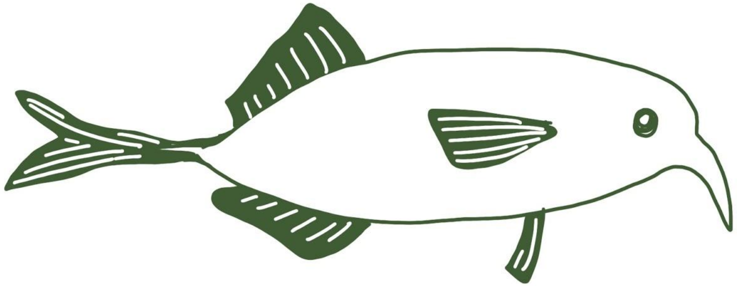

Ex: elephant nose fish

How do organisms sense electricity?

- There are two types of electrosensory systems:
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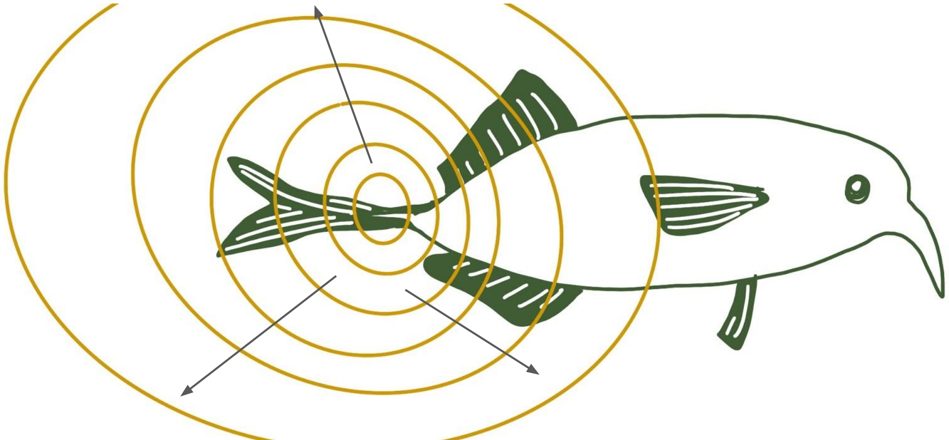

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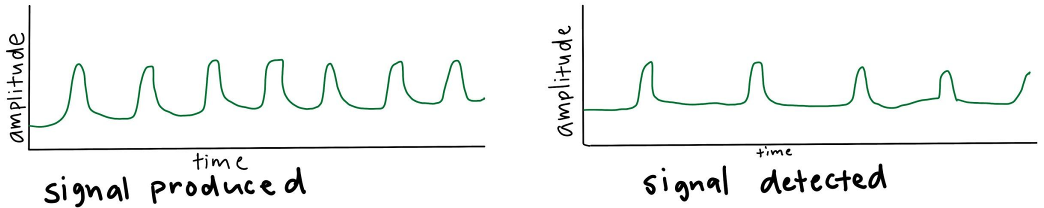

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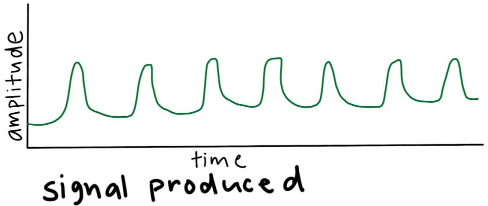
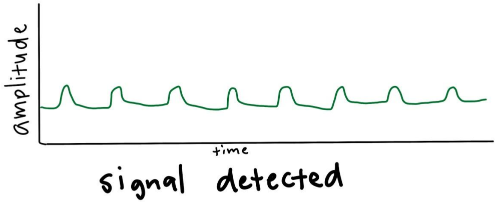


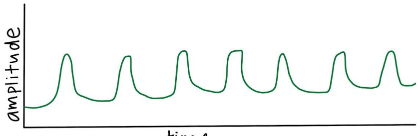


How do organisms sense electricity?

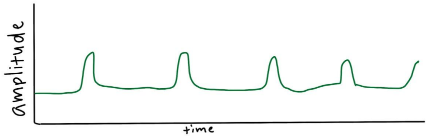
- **How is distortion of electrical signals sensed?**
    - **Tuberous receptors** detect changes in a) the **timing** of the returning electrical impulse or b) the **amplitude**
- **You should know these two examples from class:**

- **Moray Eels:**
    - Create electrical pulses at irregular intervals
    - Pay attention to the timing **and** amplitude of what comes back to figure out what's in the environment

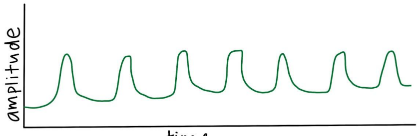
- **Elephant fish:**
    - Create regularly-timed electrical pulses
        - Can vary the amplitude of the pulse
    - Sense the difference between the amplitude of what it sends out and the amplitude that comes back, and use that to figure out what objects are in the environment



signal produced



signal detected



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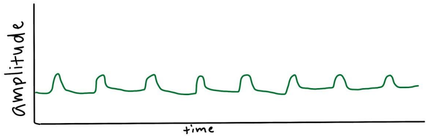

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Ribbon synapses

Ribbon synapses

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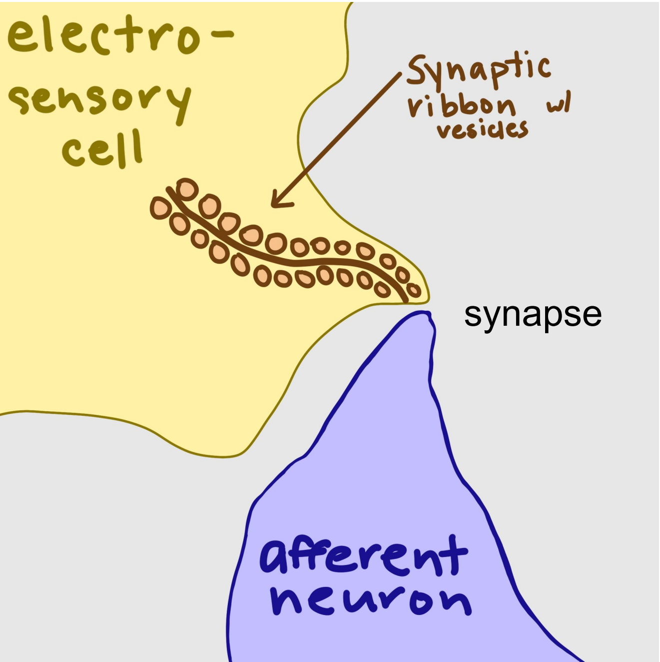

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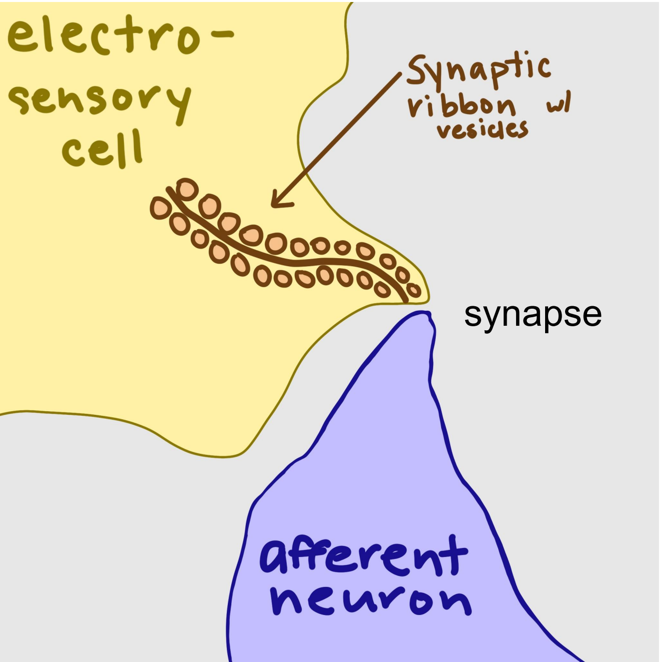

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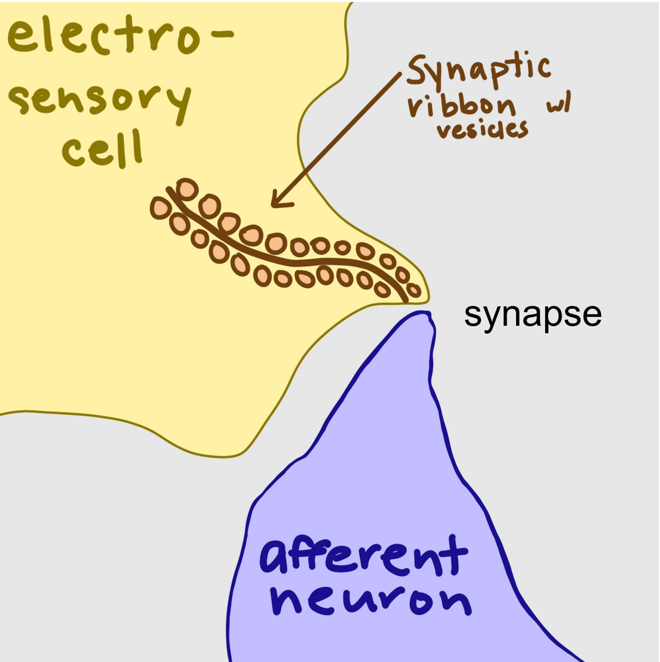

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- For more info: Bellono, N.W., Leitch, D.B. & Julius, D. Molecular tuning of electroreception in sharks and skates. *Nature* 558, 122–126 (2018) doi:10.1038/s41586-018-0160-9

From Dr. Selvaraj:

"Students should know about the electrosensory system (active and passive), the two types of active electrolocation."

Mechanosensation

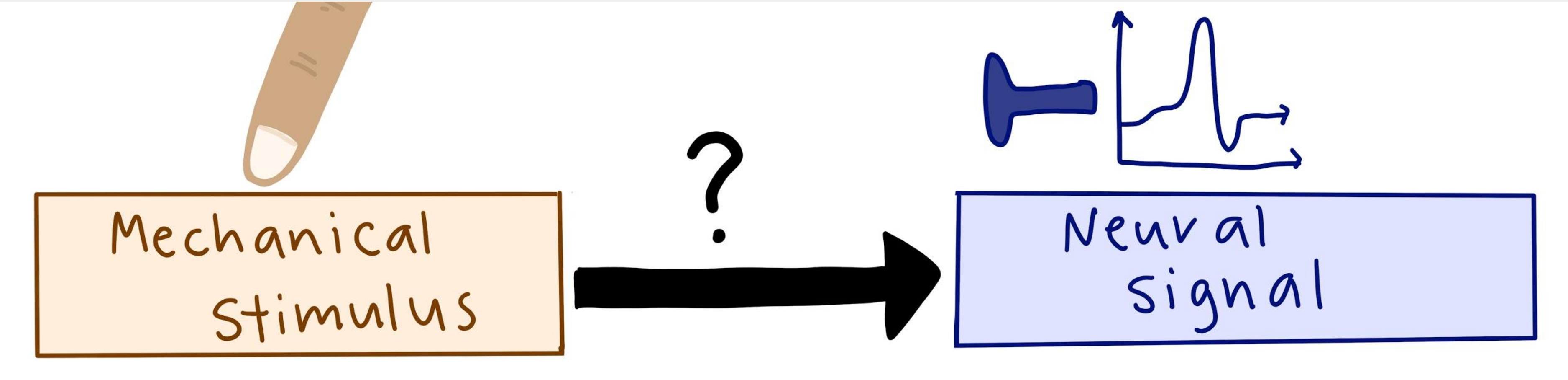
Mechanosensation

- How do cells turn a mechanical stimulus into a neural signal?
- How can organisms sense many different mechanical stimuli?

Mechanoreceptors have unique ion channels

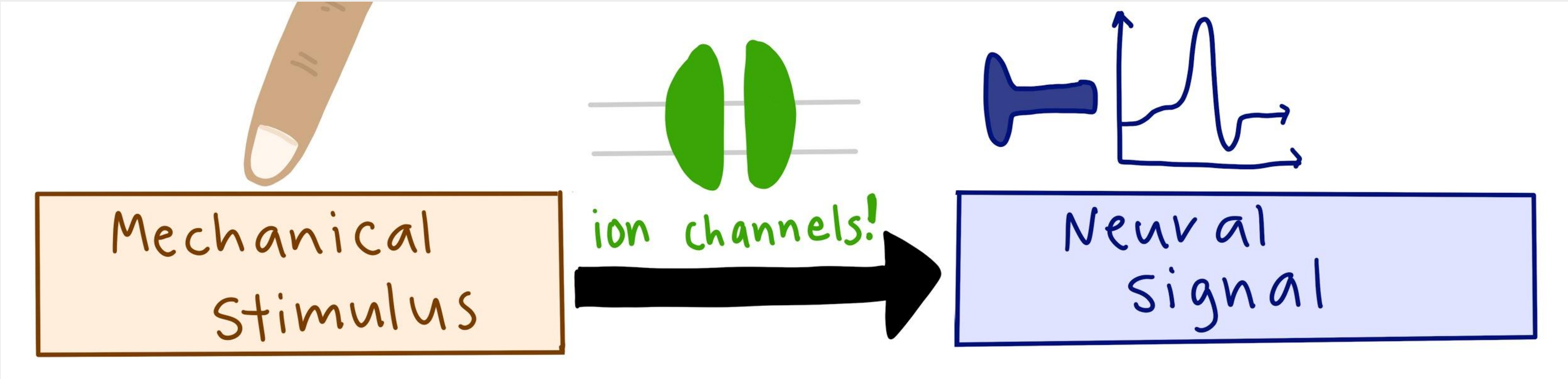
Mechanoreceptors have unique ion channels

- Mechanoreceptors must translate mechanical stimuli into a neural signal



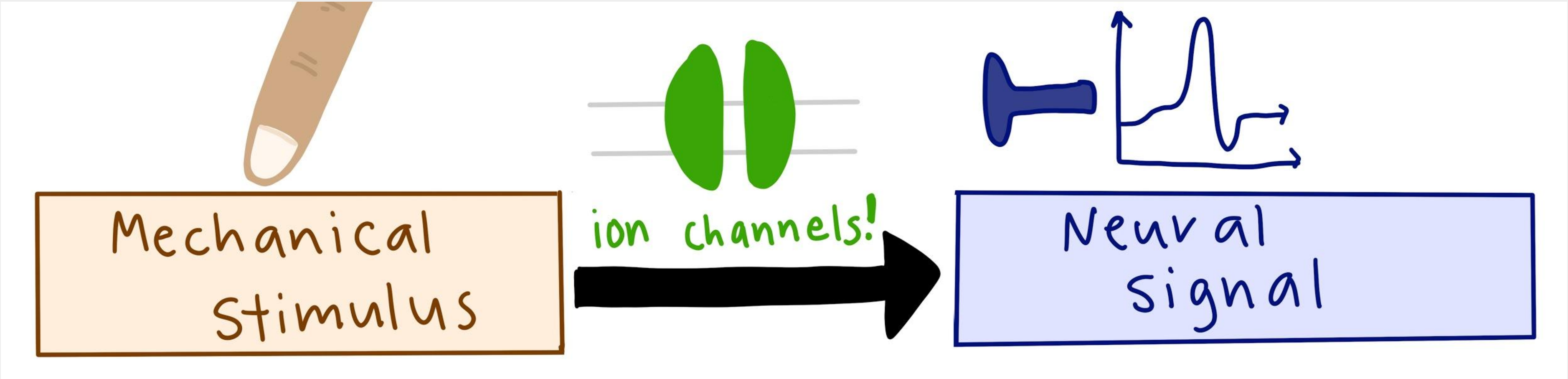
Mechanoreceptors have unique ion channels

- Mechanoreceptors must translate mechanical stimuli into a neural signal
- They do this with **special mechanosensitive ion channels**



Mechanoreceptors have unique ion channels

- Mechanoreceptors must translate mechanical stimuli into a neural signal
- They do this with **special mechanosensitive ion channels**
    - There are two groups of these channels whose names you should know:
        - **Transient receptor potential channels**
        - **Piezo genes**



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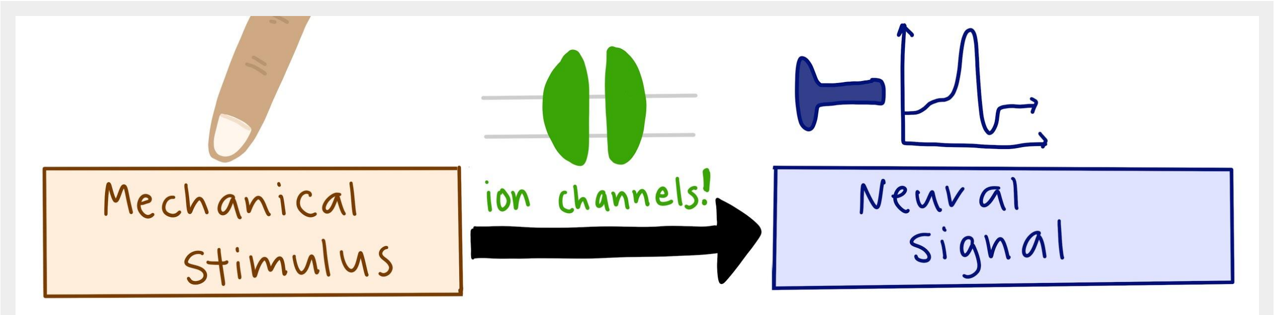

Mechanoreceptors have unique ion channels

Dr. Selvaraj specifically mentioned this in his study guide.

- Mechanorecep ... ral signal
- They do this v ...
  - There are ... should know:
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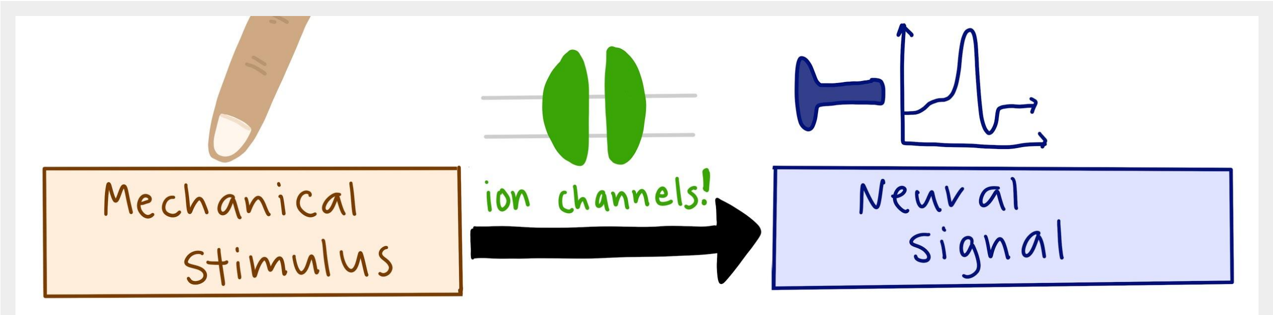


Mechanoreceptors have unique ion channels

-

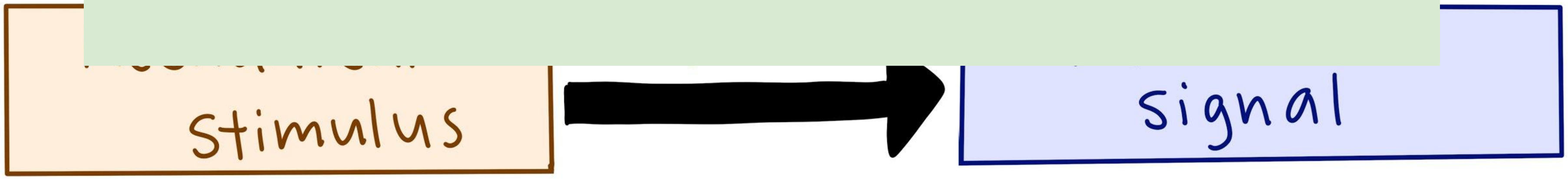
- now:

For more info if you're curious:

https://www.britannica.com/science/transient-receptor-potential-channel

https://www.cell.com/current-biology/pdf/S0960-9822(17)30083-0.pdf

This one is an especially good reference for understanding mechanoreception.



Mechanoreceptors are found in the skin.

General anatomy of skin

This is extra background information not covered directly in the in-class lecture.

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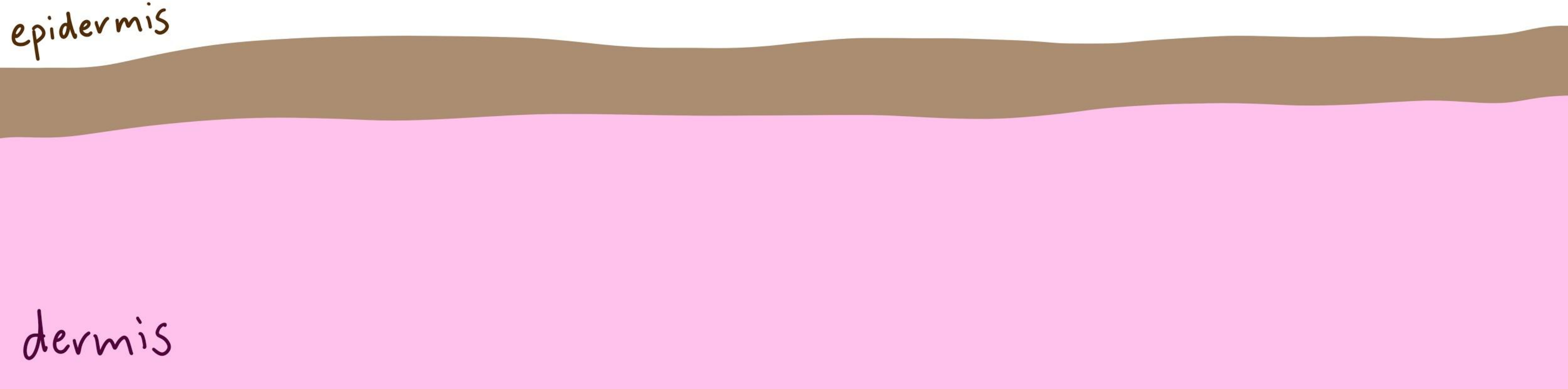
- Two major layers:
    - Dermis: most external



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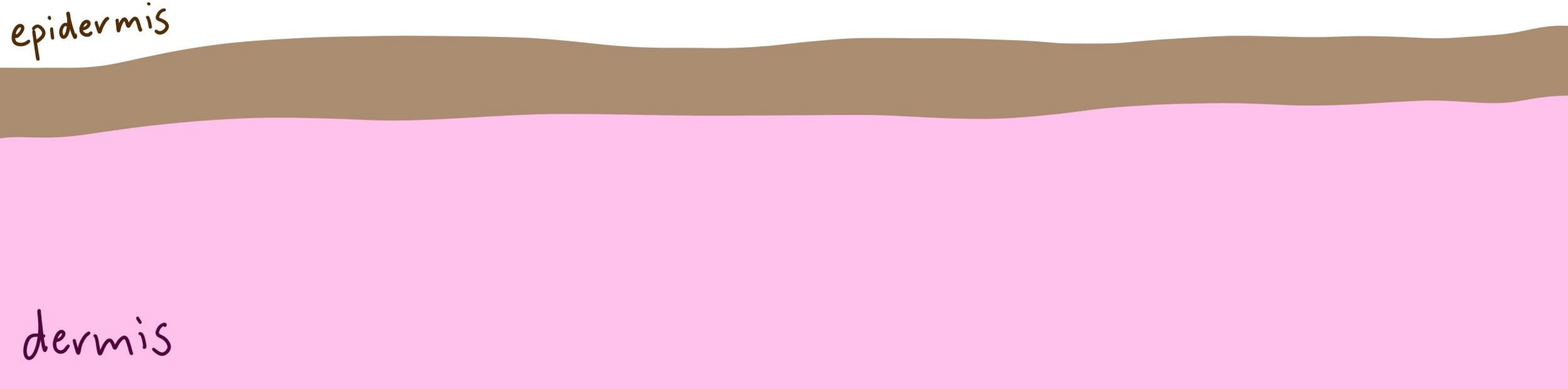
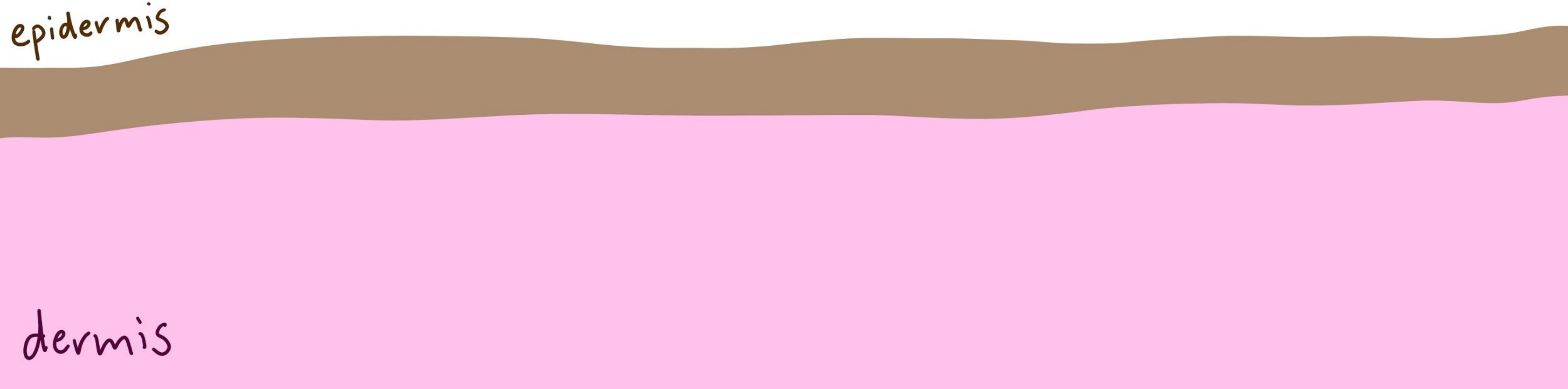


General anatomy of skin

This is extra background information not covered directly in the in-class lecture.

- Two major layers:
    - Dermis: most external
    - Epidermis
        - Composed of three sublayers, which you don't need to know



Types of skin

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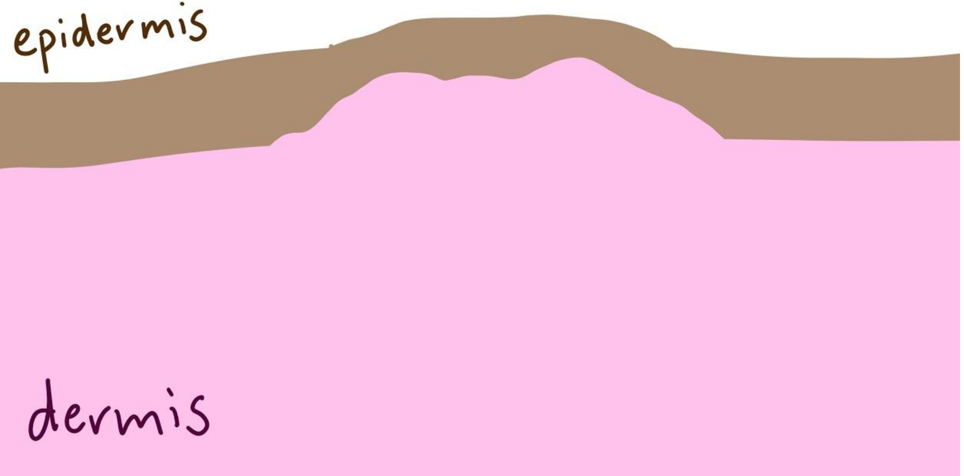
    - **Glabrous** (nonhairy): lips, palms, feet, parts of genitals



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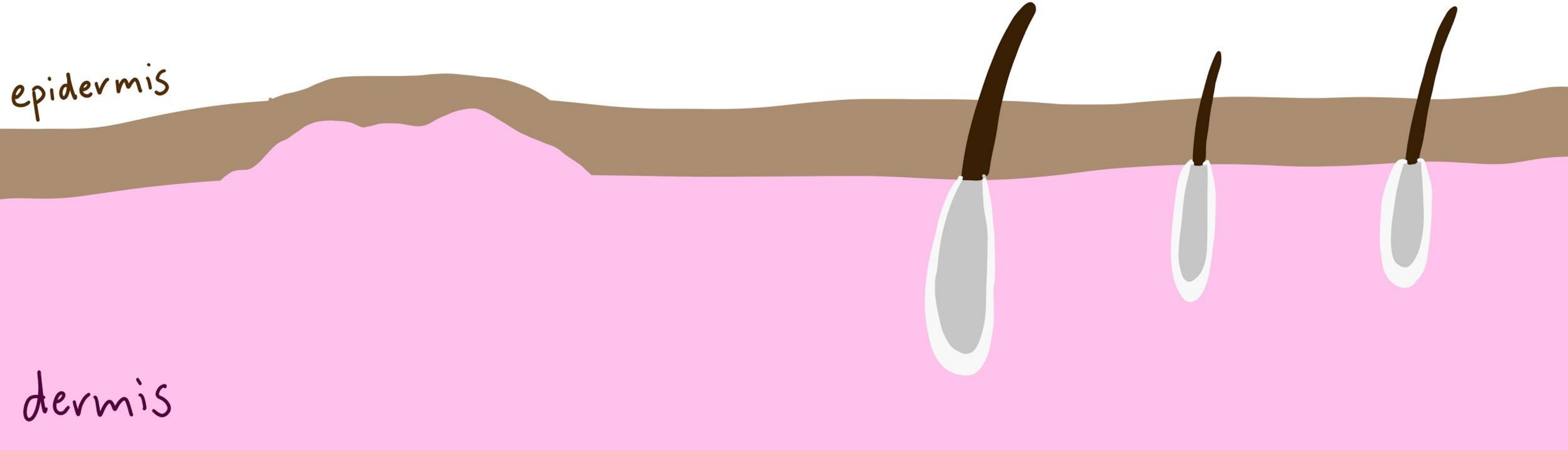
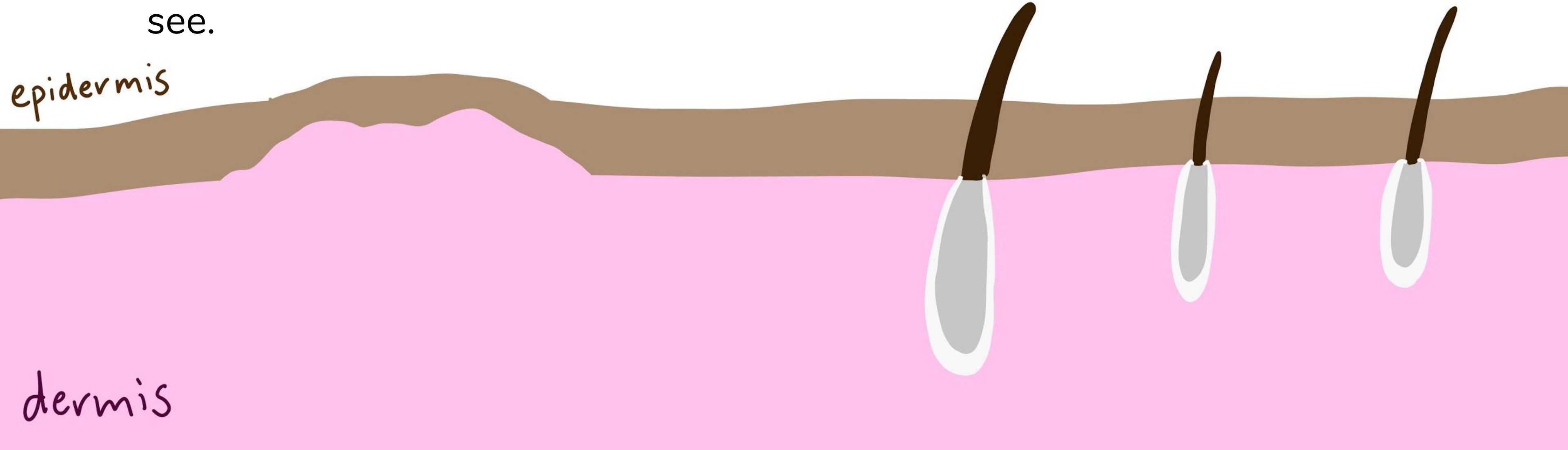


Types of skin

- Mammals have two types of skin:
    - **Glabrous** (nonhairy): lips, palms, feet, parts of genitals
    - **Hairy**: basically everywhere else
- These types of skin have distinct types of mechanoreceptor cells, as you will see.



Mechanoreceptors of glabrous skin

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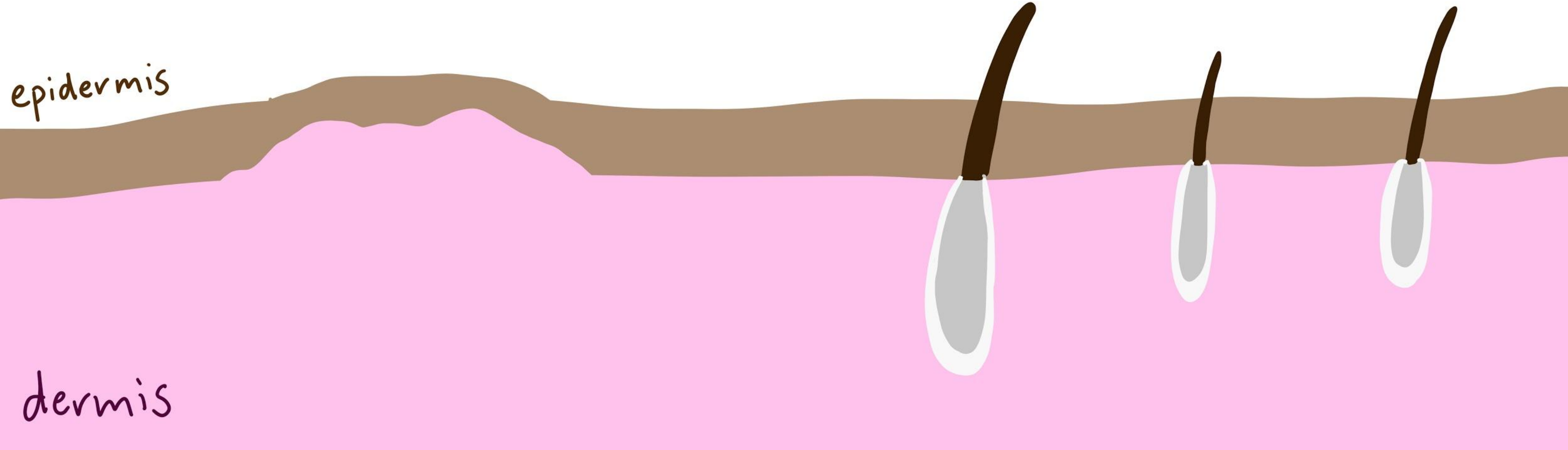
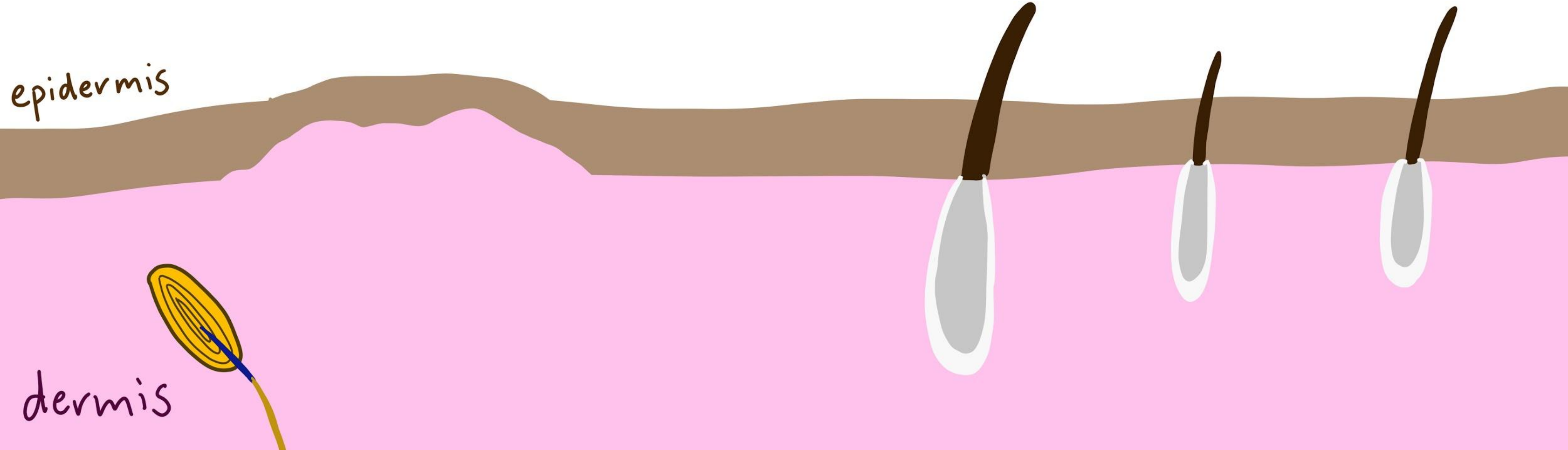
- Glabrous skin has four major mechanoreceptors:



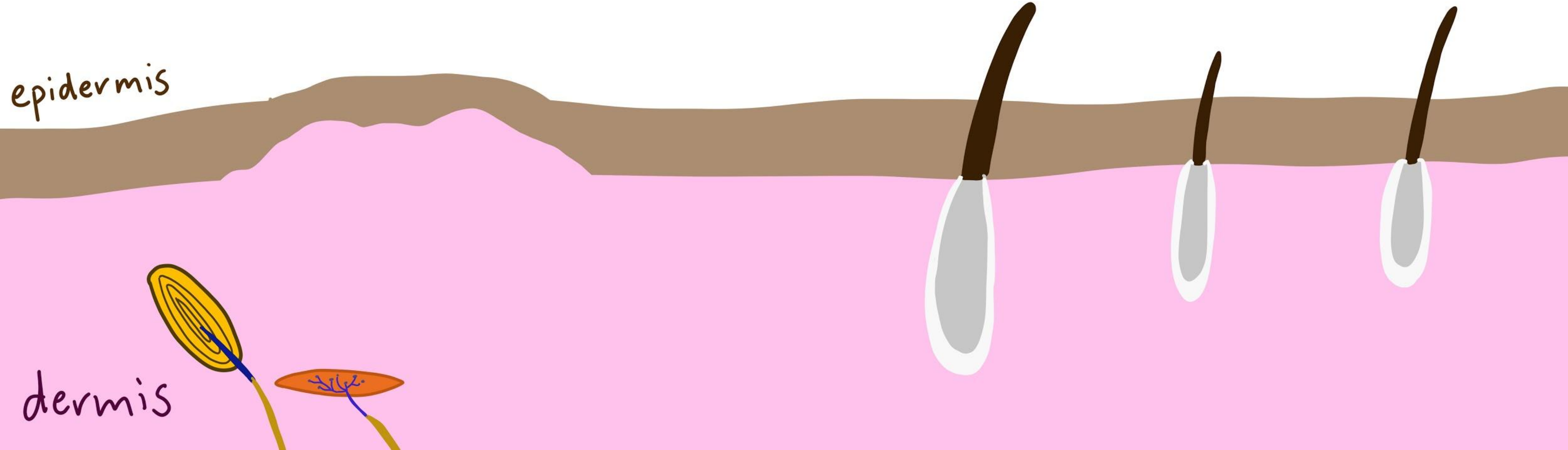
Mechanoreceptors of glabrous skin

- Glabrous skin has four major mechanoreceptors:
  - **Pacinian corpuscles**: located in the dermis.
    - These are **phasic** receptors that sense **vibrations**, as deformation of the dermis causes their membranes to leak sodium ions and send action potentials.



Mechanoreceptors of glabrous skin

- Glabrous skin has four major mechanoreceptors:
  - **Pacinian corpuscles**: **phasic** receptors that sense **vibrations**.
  - **Ruffini endings**: located in the deep dermis (also in hairy skin).
    - These are **tonic** receptors that respond to **skin stretching/deformation**.



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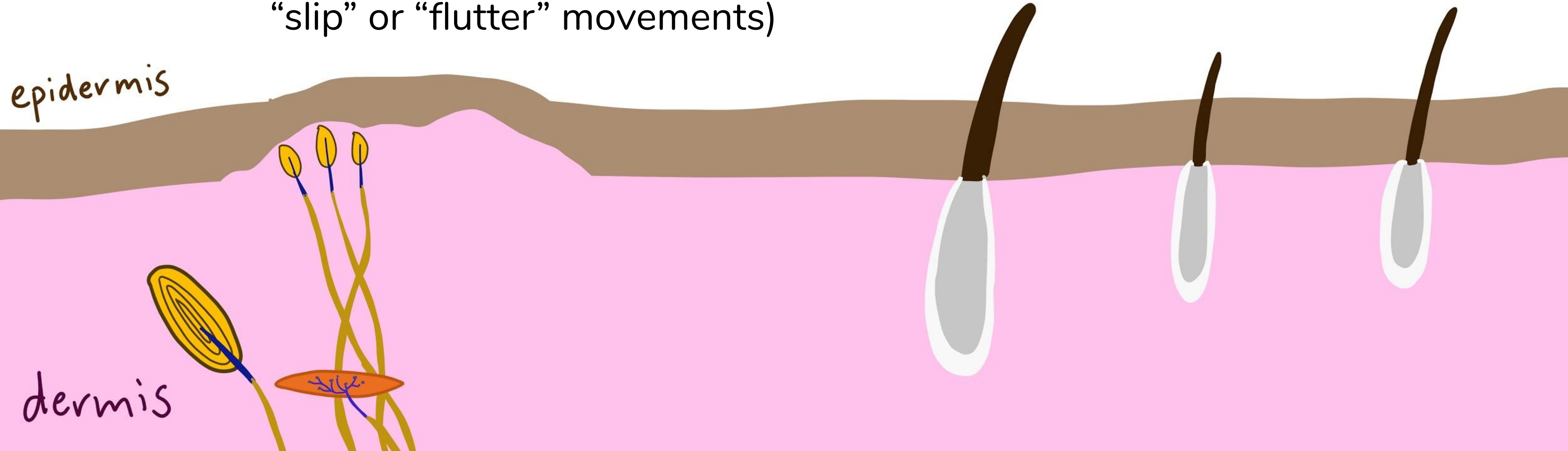
    - **Pacinian corpuscles**: **phasic** receptors that sense **vibrations**.
    - **Ruffini endings**: **tonic** receptors that respond to **skin stretch/deformation**.
    - **Meissner corpuscles**: found high in the dermis (also in hairy skin).
        - **Phasic** receptors that detect **movement across the skin** (described as “slip” or “flutter” movements)



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  - **Meissner corpuscles**: **phasic** receptors that detect **movement across skin**
  - **Merkel's discs**: in the basal layer of the epidermis (also in hairy skin). **Tonic** receptors that sense **indentation at a very fine scale**.

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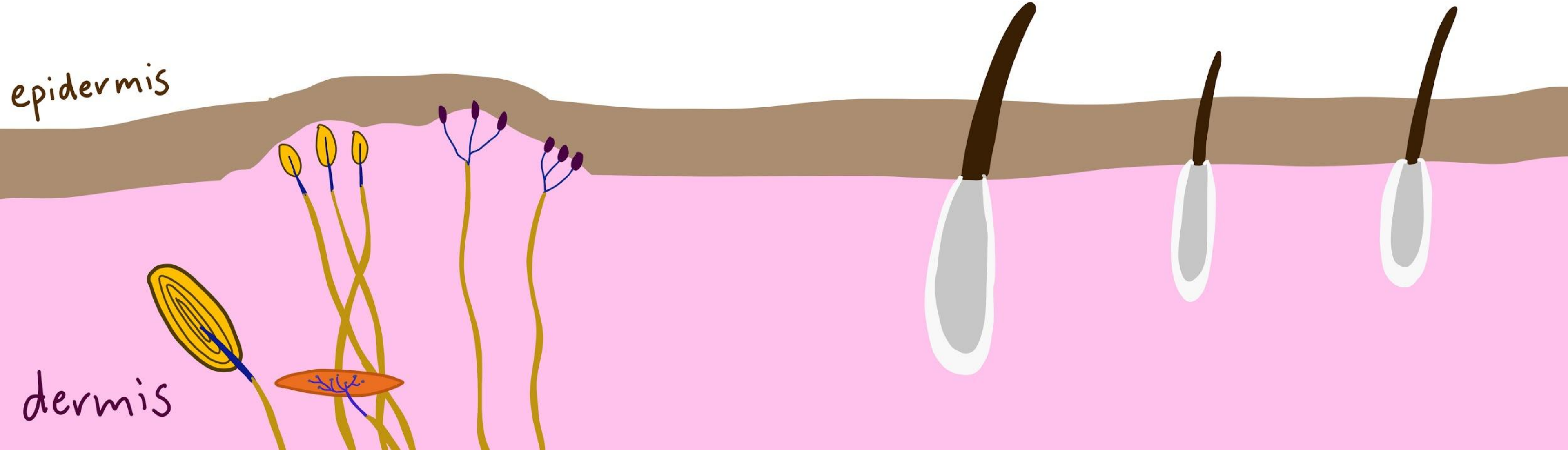
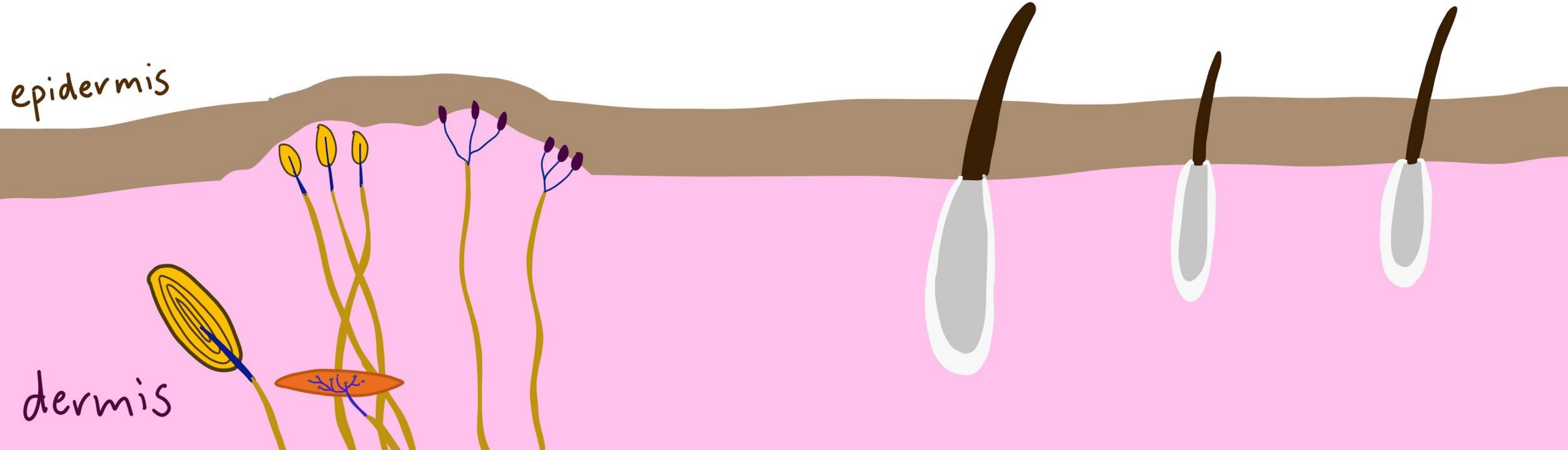


Mechanoreceptors of hairy skin

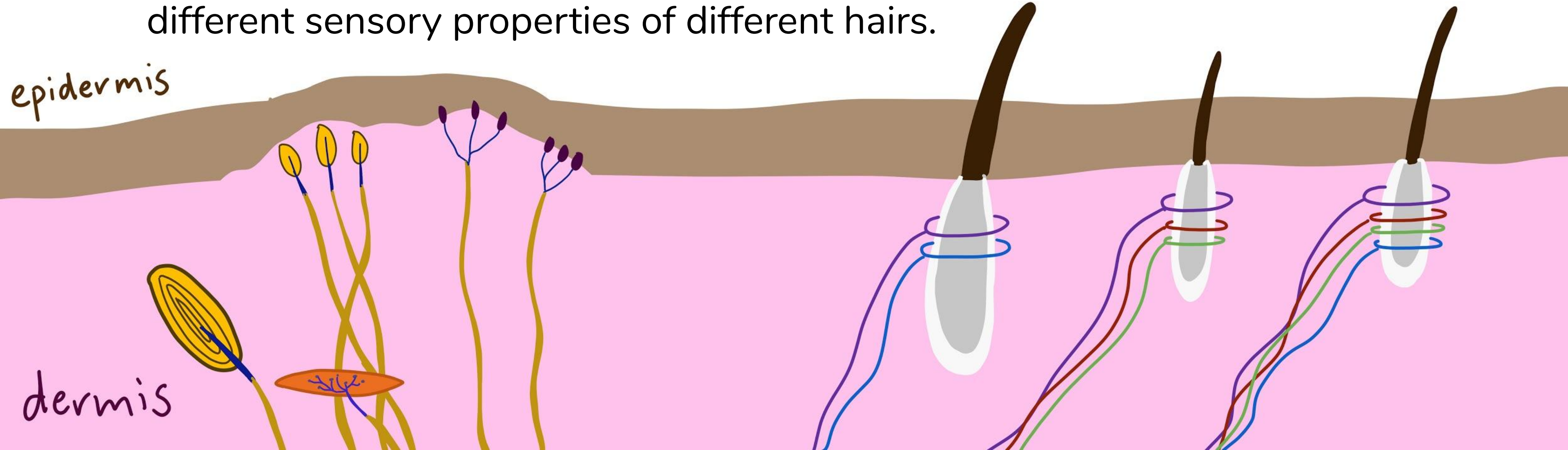
Mechanoreceptors of hairy skin

- There is a specialized group of mechanoreceptors associated with hair follicles that you need to know.



Mechanoreceptors of hairy skin

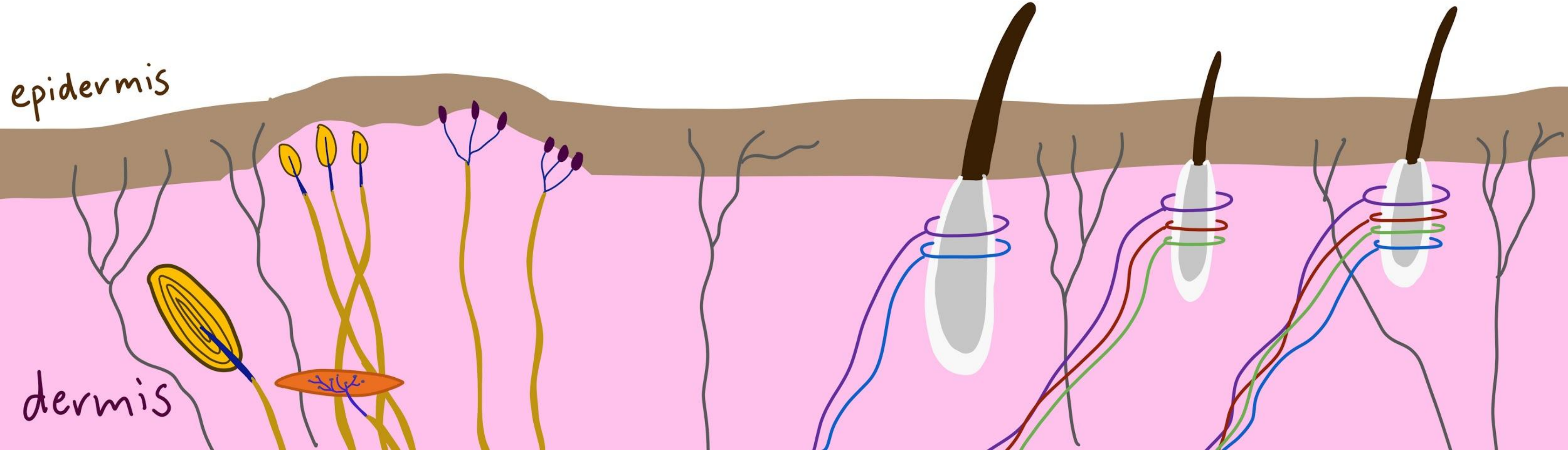
- There is a specialized group of mechanoreceptors associated with hair follicles that you need to know.
- **Longitudinal lanceolate endings**: **tonic** receptors that surround the follicle and detect **when the hair bends**. Different combinations give rise to the different sensory properties of different hairs.



Free nerve endings

Free nerve endings

- These are found in both types of skin.



Free nerve endings

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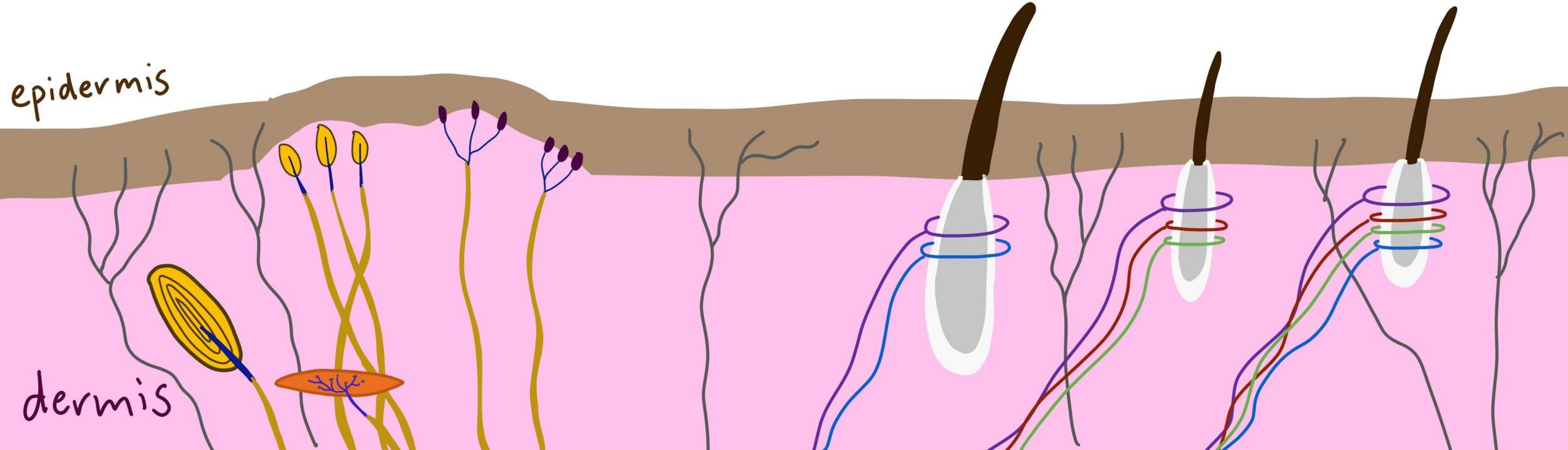
- They detect “**noxious touch**” which mostly means **pain**.



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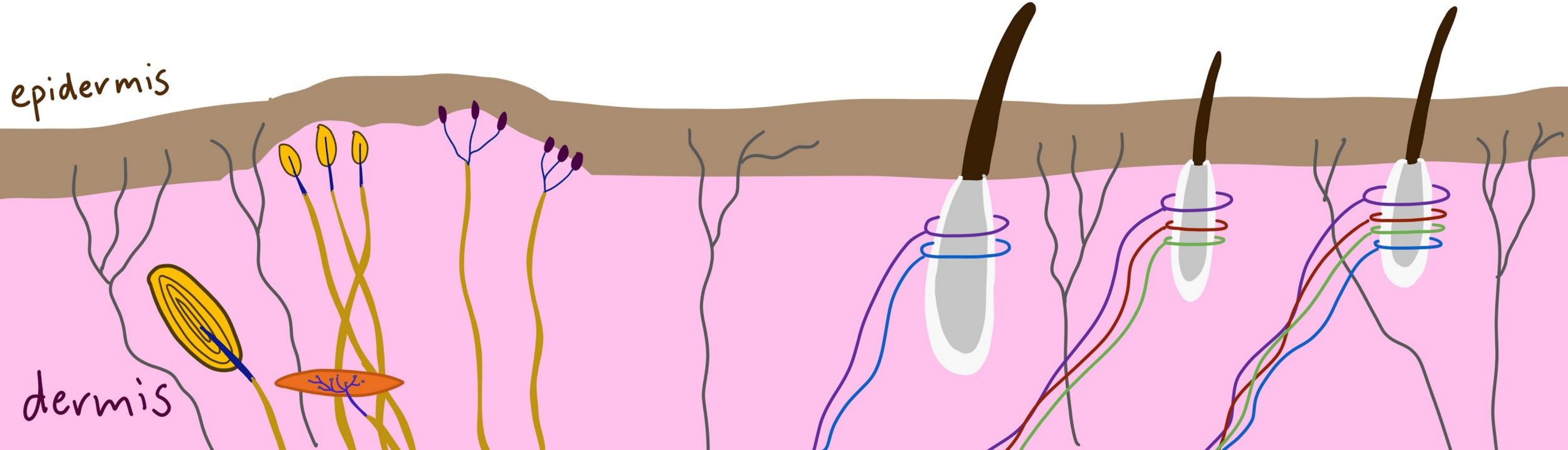

Mechanoreceptors you need to memorize:

End organ	Skin type	Stimulus	Type of response
Pacinian corpuscle	Glabrous (nonhairy)	High-frequency vibration	Phasic
Ruffini ending	Both	Skin stretching	Tonic
Meissner corpuscle	Both	Movement across the skin	Phasic
Merkel's disc	Both	Indentation	Tonic
Longitudinal lanceolate endings	Hairy	Hair follicle deflection	Tonic
Free nerve endings	Both	"Noxious mechanical" aka pain	Tonic

Mechanoreceptors you need to memorize:

End organ	Skin type	Stimulus	Type of ... sponse
Pacinian corpuscle	Glabrous (nonhair...)		
R...			
Me...			
Me...			
Lon... lanc...			
Free...		“Noxious mechanical” aka pain	Tonic

According to Dr. Selvaraj, you 100% need to memorize this information, so make flashcards and start practicing with them.

You **DO NOT** need to know the physiological subtypes or the associated fibers listed in the lecture slides.

Practice questions:

You are holding a vibrating sander for a while as you refinish your floor. After a while, you realize that you are no longer sensing the vibrations in your hand. Why is this?

a. The vibrations damaged mechanoreceptors in your hand.
b. The vibrations are too small for the receptive fields of your Pacinian corpuscles.
c. Pacinian corpuscles are phasic receptors.
d. The stimulus is above the saturation point for your Pacinian corpuscles.

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Practice questions:

You are holding a vibrating sander for a while as you refinish your floor. After a while, you realize that you are no longer sensing the vibrations in your hand. Why is this?

a. The vibrations damaged mechanoreceptors in your hand.
    i. This is highly unlikely, and would require very very strong vibrations for a really long time. Plus, you would feel pain if this happened.
b. The vibrations are too small for the receptive fields of your Pacinian corpuscles.
    i. There is no such thing as a stimulus that is spatially too small for a receptive field; you would simply sense it as a single stimulus.
c. **Pacinian corpuscles are phasic receptors.**
d. The stimulus is above the saturation point for your Pacinian corpuscles.
    i. You would still feel the vibrations if this was the case; you simply would not be able to detect if they were getting **more intense.**

Practice questions:

Cats are able to take in lots of information about the world around them via their whiskers. Why would this be the case?

a. Whiskers are hair follicles with lots of longitudinal lanceolate endings.
b. Whiskers are in glabrous skin that has many free nerve endings.
c. The mechanoreceptors surrounding cat whiskers are very phasic.
d. Whiskers are hair follicles with lots of Pacinian corpuscles.

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Cats are able to take in lots of information about the world around them via their whiskers. Why would this be the case?

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b. Whiskers are in glabrous skin that has many free nerve endings.
    i. Free nerve endings detect pain, which is generally not a stimulus used to construct a map of the surrounding world.
c. The mechanoreceptors surrounding cat whiskers are very phasic.
    i. Phasic receptors adapt rapidly and stop transmitting signals, which would not be useful for building a map of the world
d. Whiskers are hair follicles with lots of Pacinian corpuscles.
    i. Pacinian corpuscles are not found in hairy skin.