Sensory systems

10/19/2013

How do we create a representation of the world?

http://www.youtube.com/watch?v=Xo9bwQuYrRo

Sensory Transduction

energy ⇨ cellular signals ⇨ action potentials

light

heat

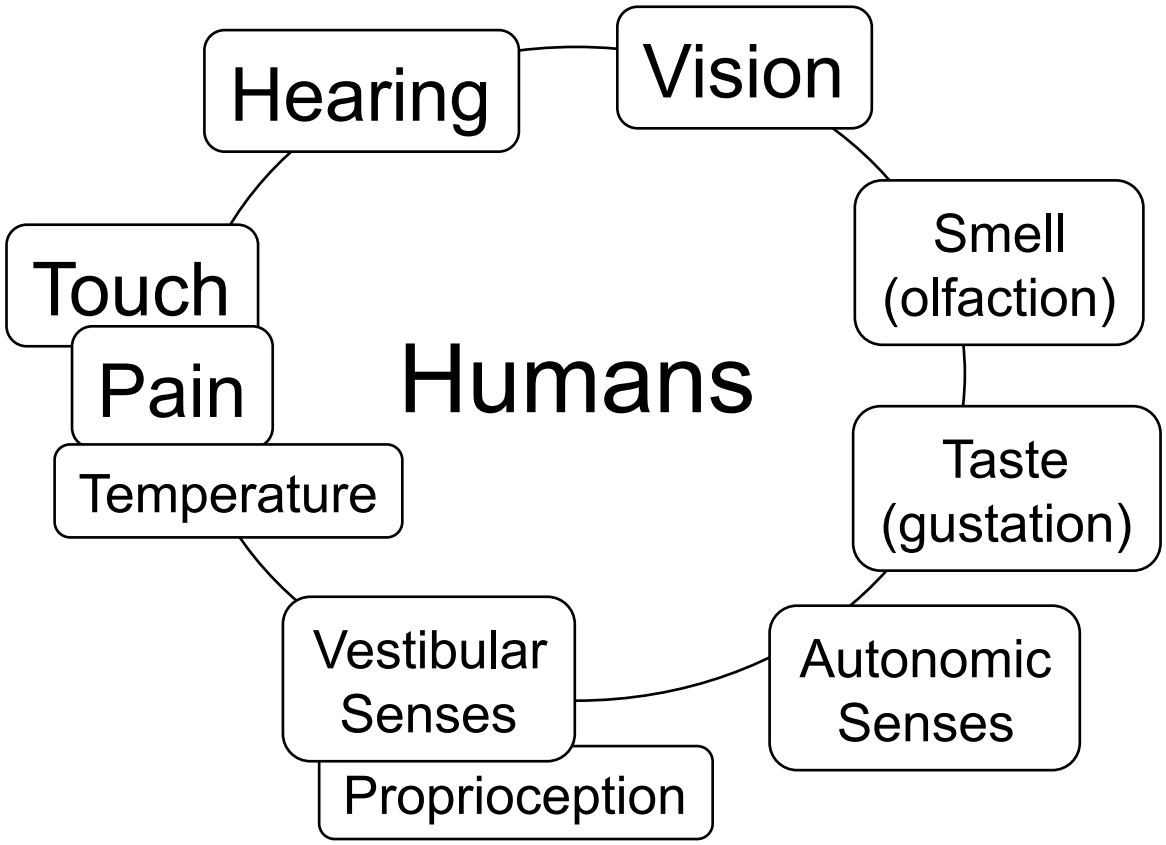
chemical

electrical

vibration

gravity

magnetic


Humans
Vision
Hearing
Smell
(olfaction)
Touch
Pain
Temperature
Taste
(gustation)
Vestibular
Senses
Autonomic
Senses
Proprioception

Basic principles in sensory transduction…

sensitivity (detection threshold)

receptive fields

adaptation

tuning ≈ specificity ≈ feature detection

timing

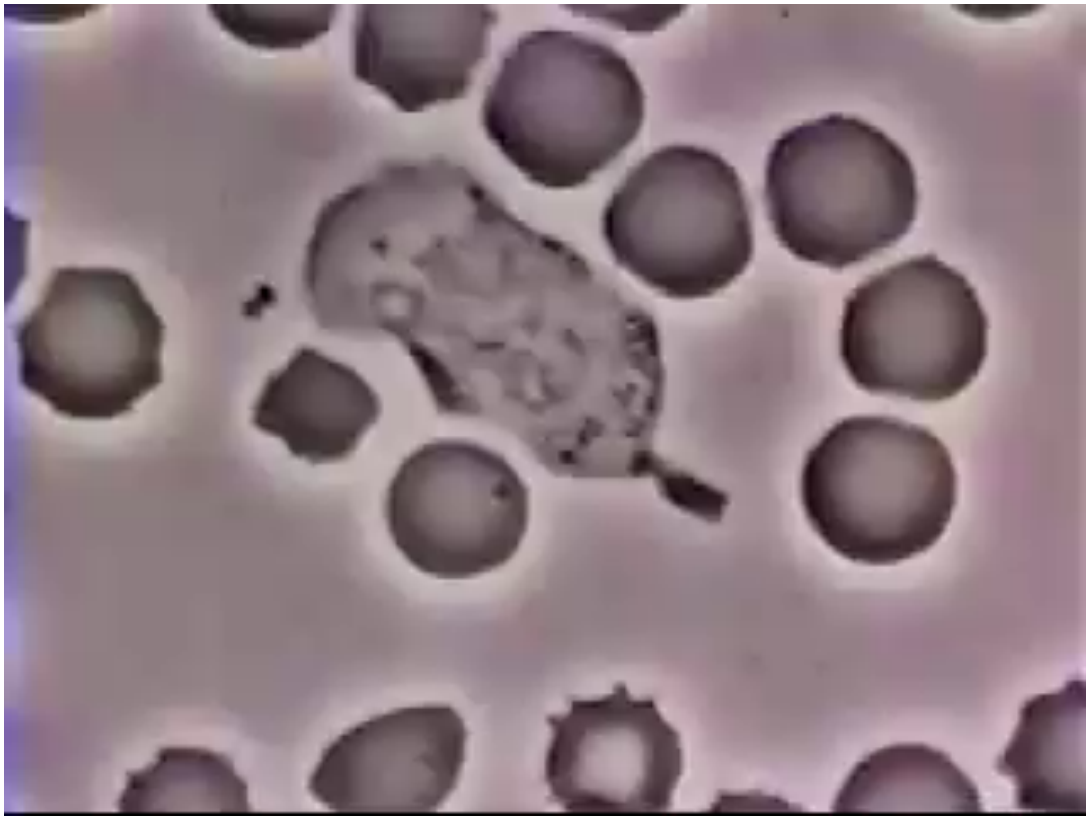
"receptors" = sensory cells *or* their sensing proteins (sometimes confusing)

The Earliest “Senses”

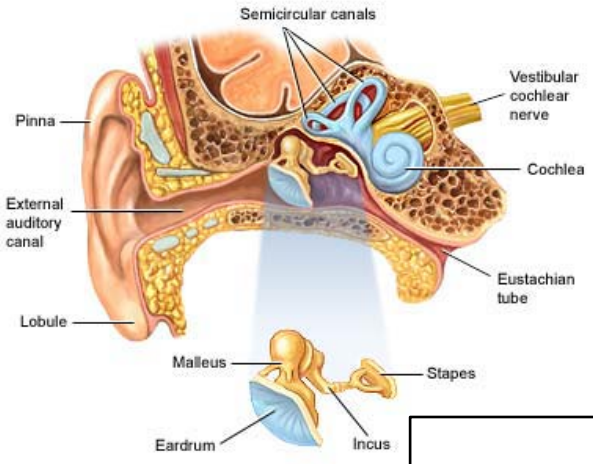
prokaryotes can detect:

chemicals
- food/metabolites
- noxious molecules
- signals

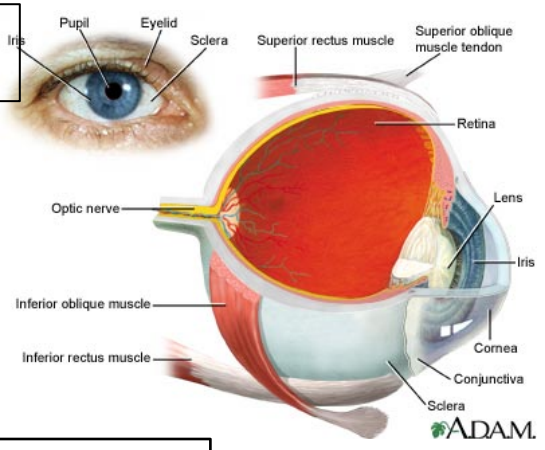
osmolarity
pH
pressure
gravity
magnetic fields
temperature



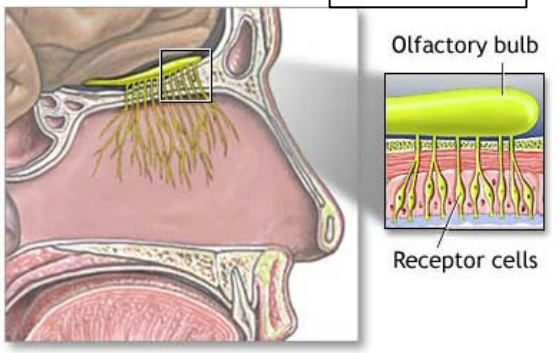
Ear



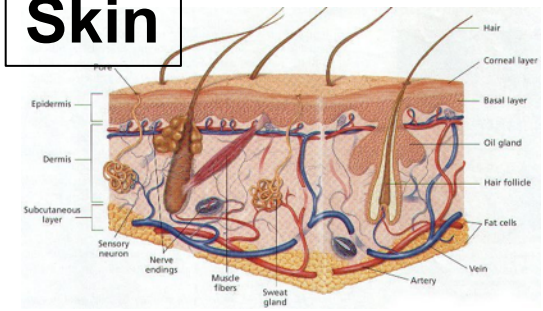
Eye

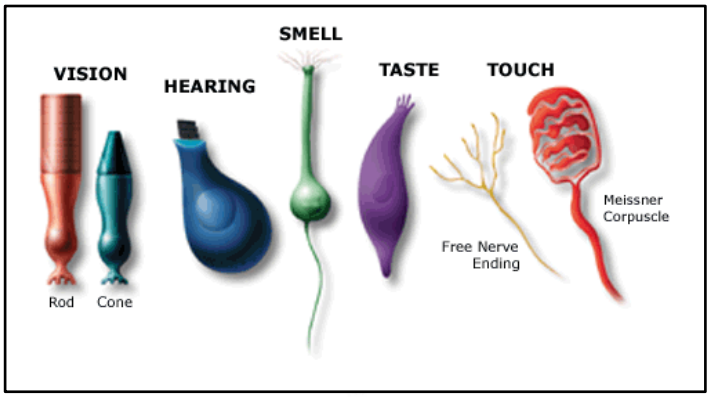


Nose

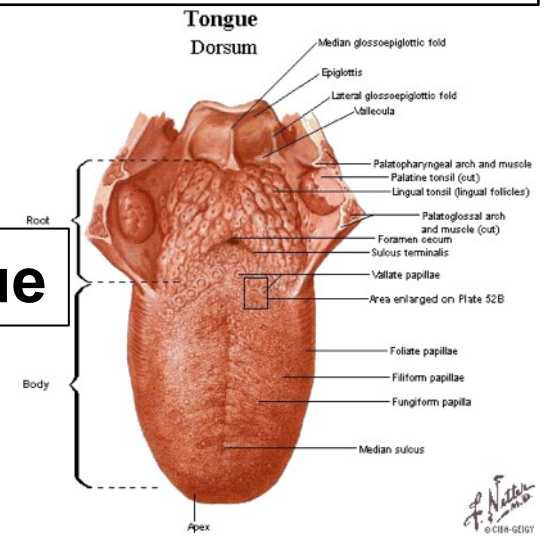


Skin

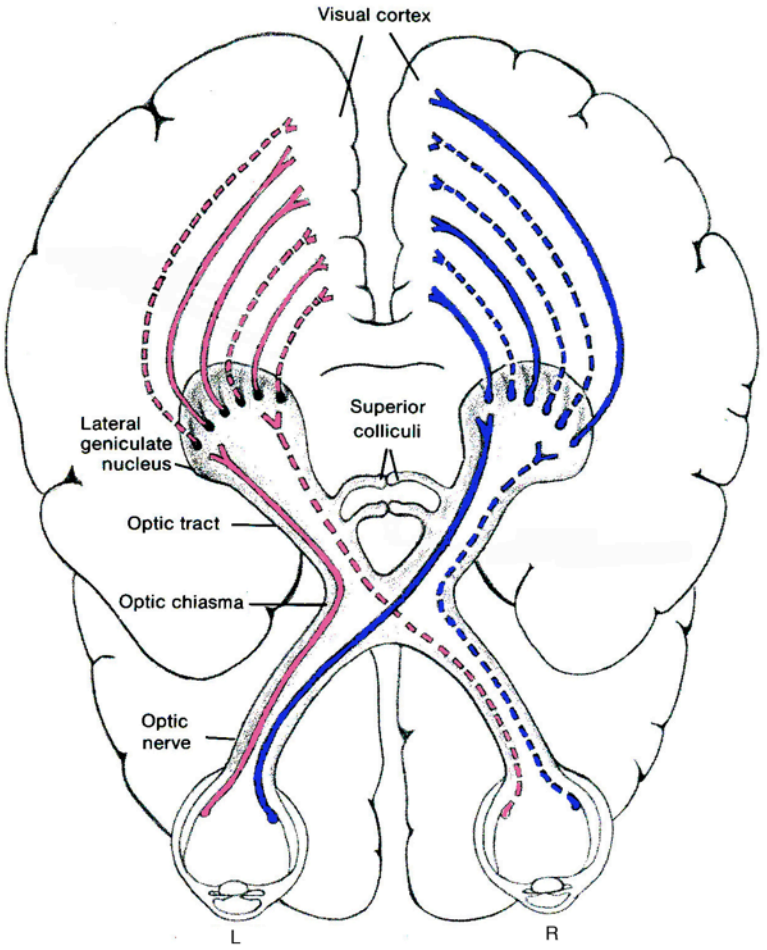




Tongue



Vision: *Where* do we see?



The eye

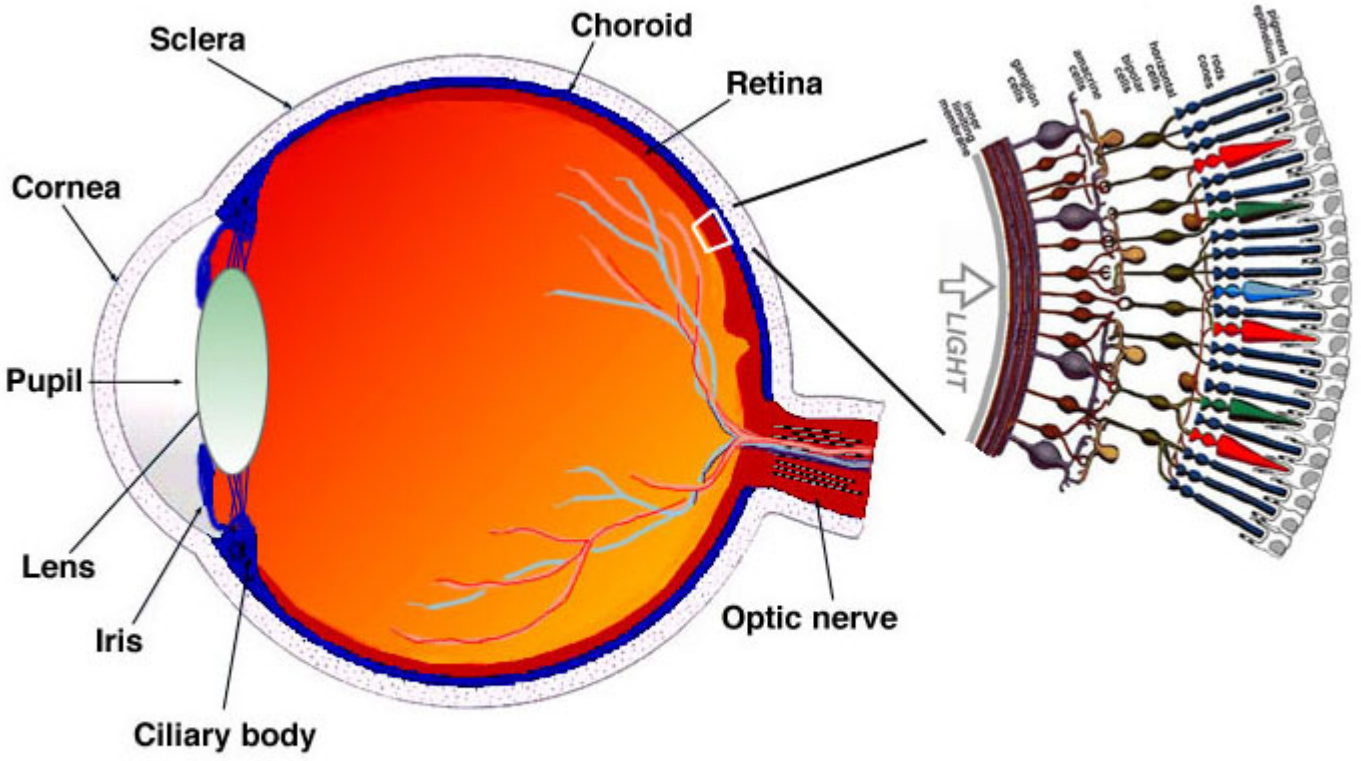
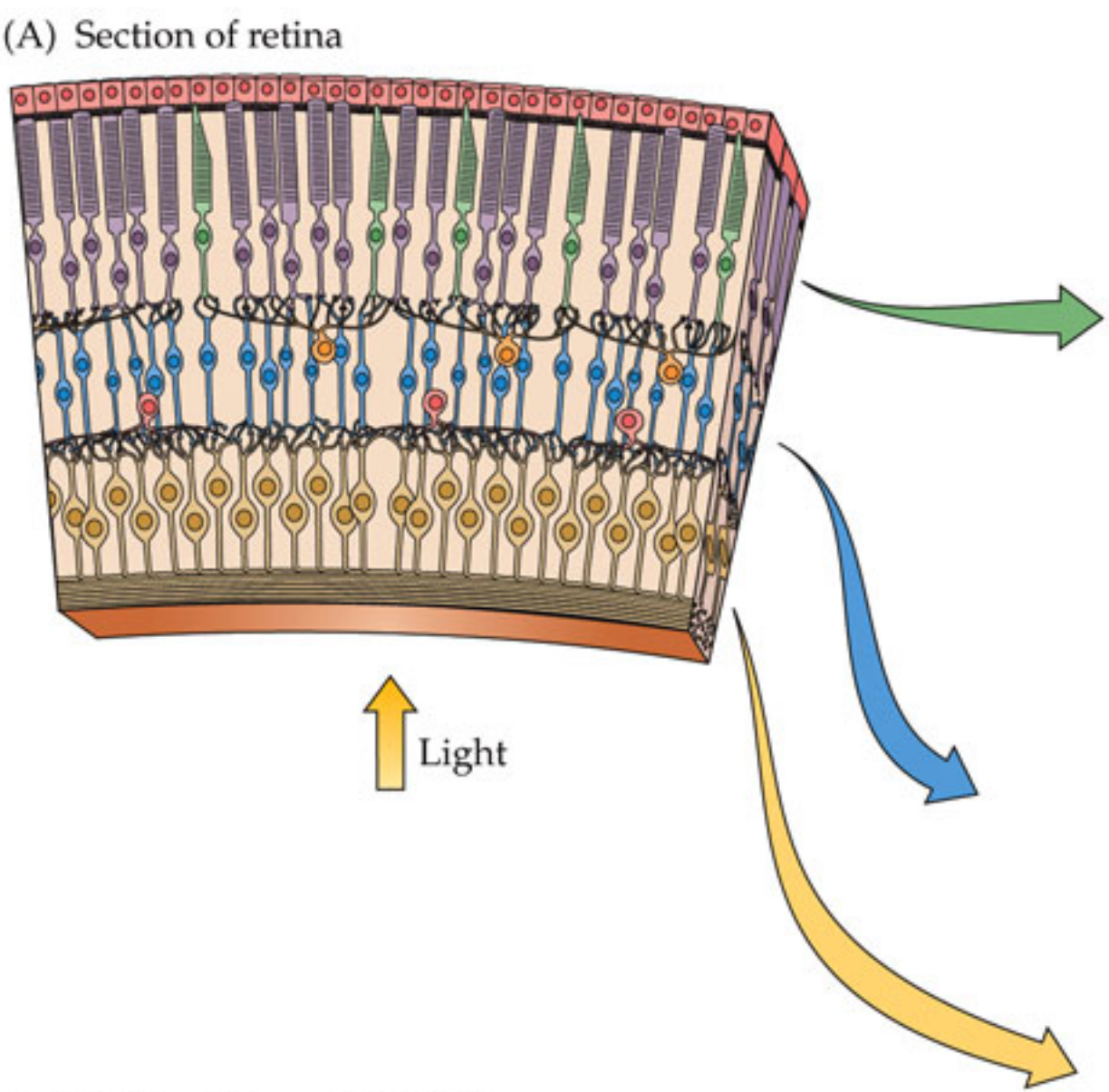
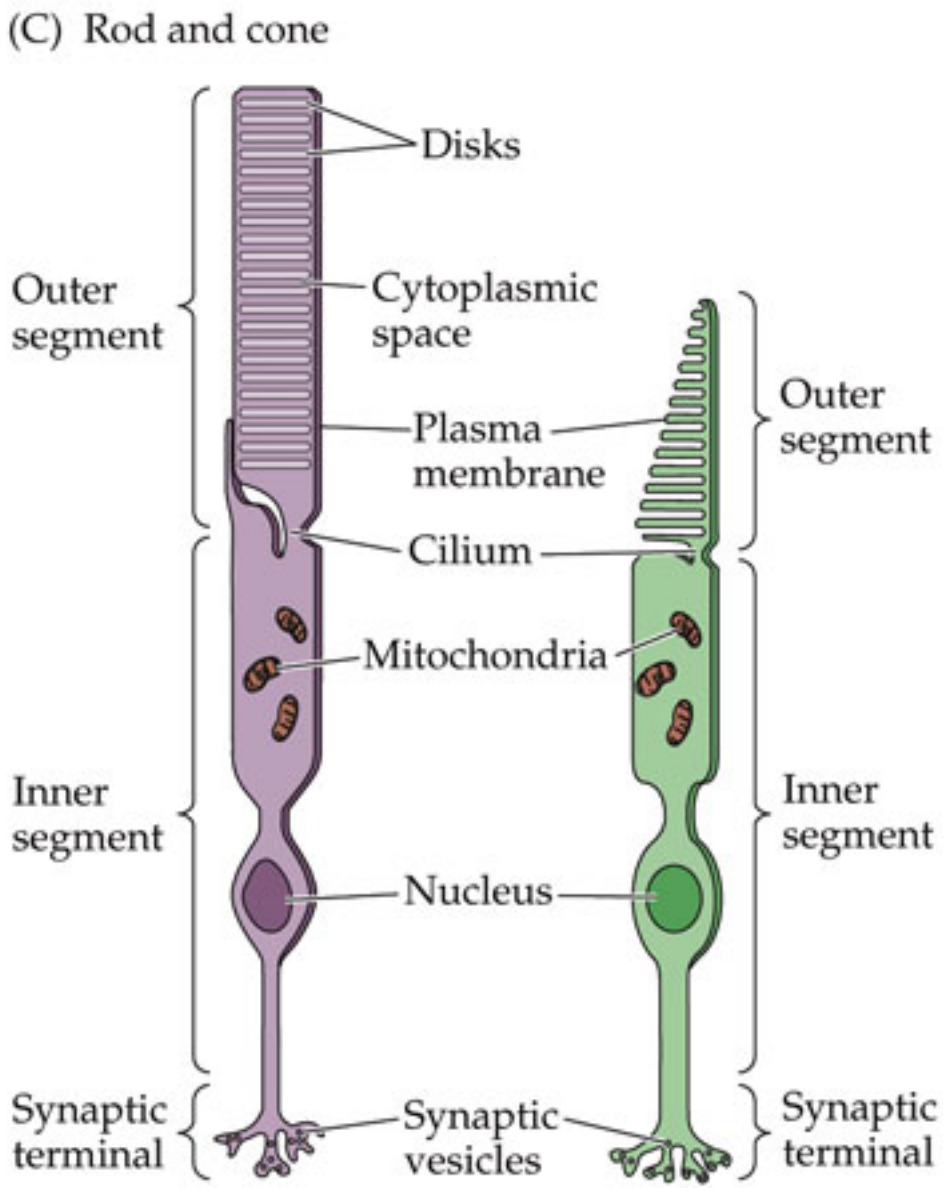


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.



***NEUROSCIENCE, Fourth Edition,* Figure 11.5 (Part 1)**



Cones for color vision
Rods for

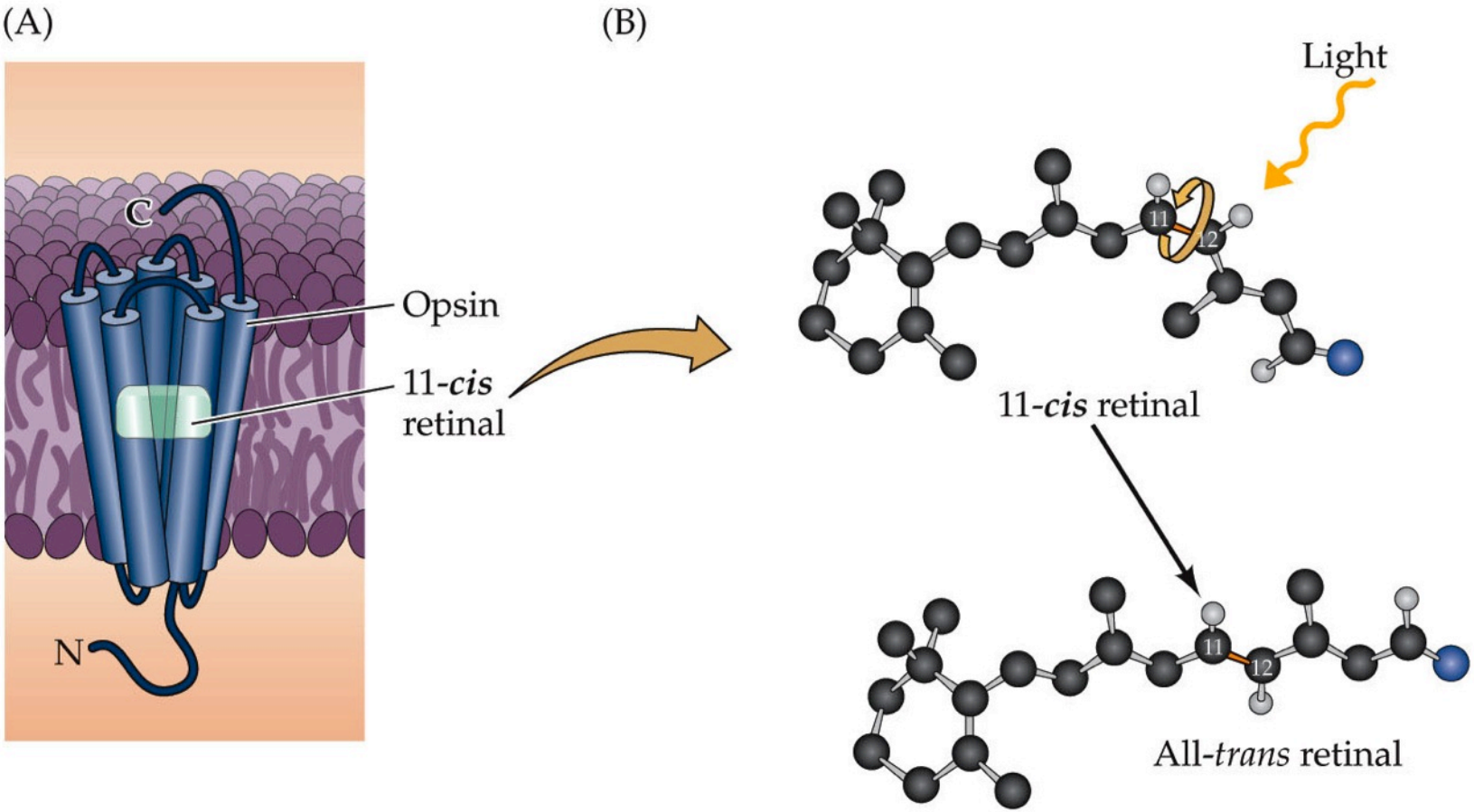
***NEUROSCIENCE, Fourth Edition*, Figure 11.5 (Part 3)**

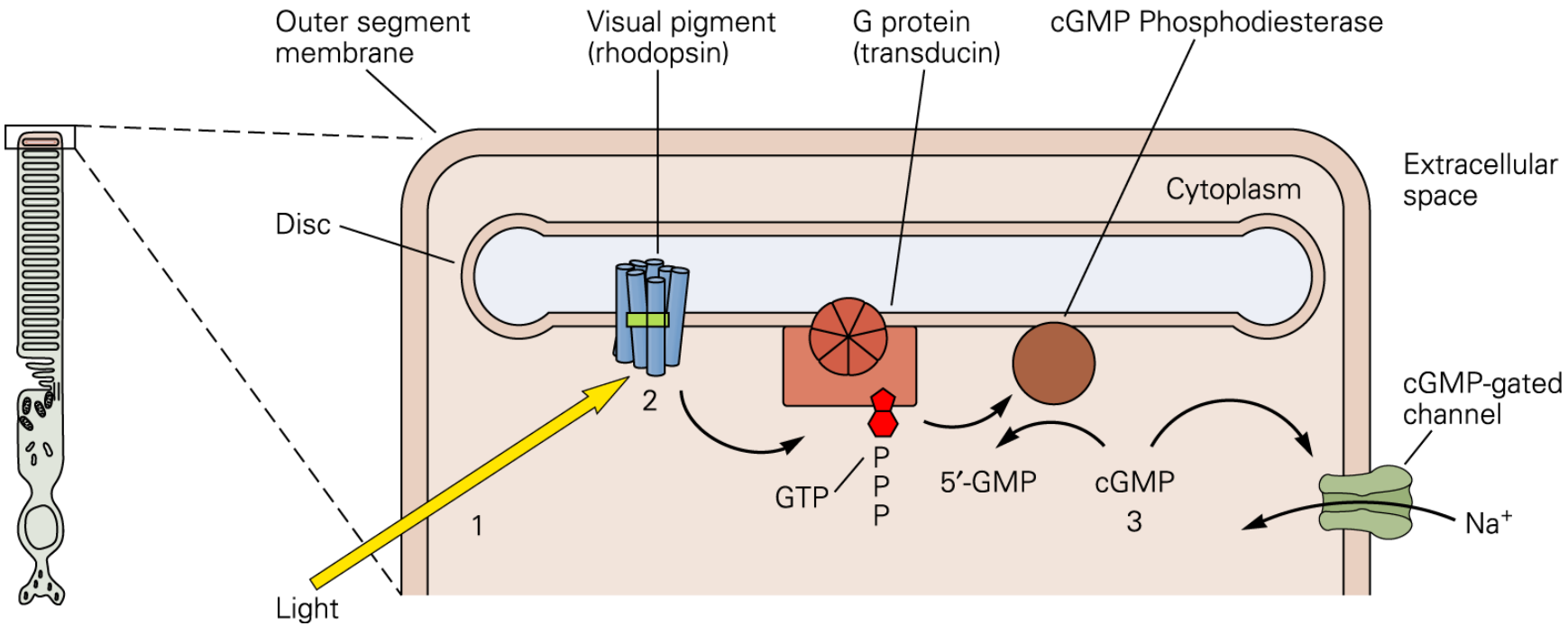
Ok, so we now know that rods and cones in the retina detect light

But how!?!?!

From light to neural signals

Opsins



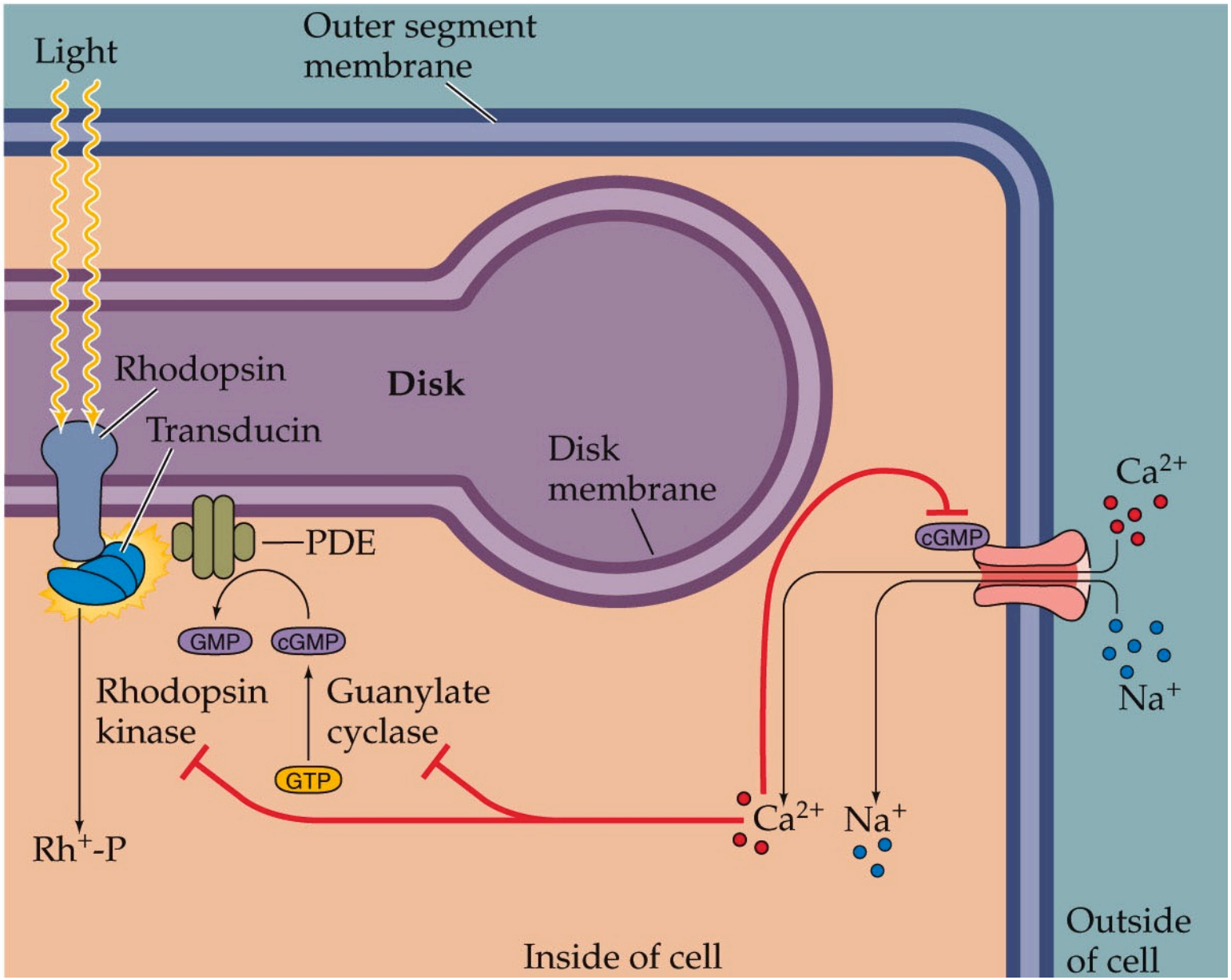


Activation of one rhodopsin with one photon of light can activate many G proteins and convert many GMPs to cGMPs and gate many channels

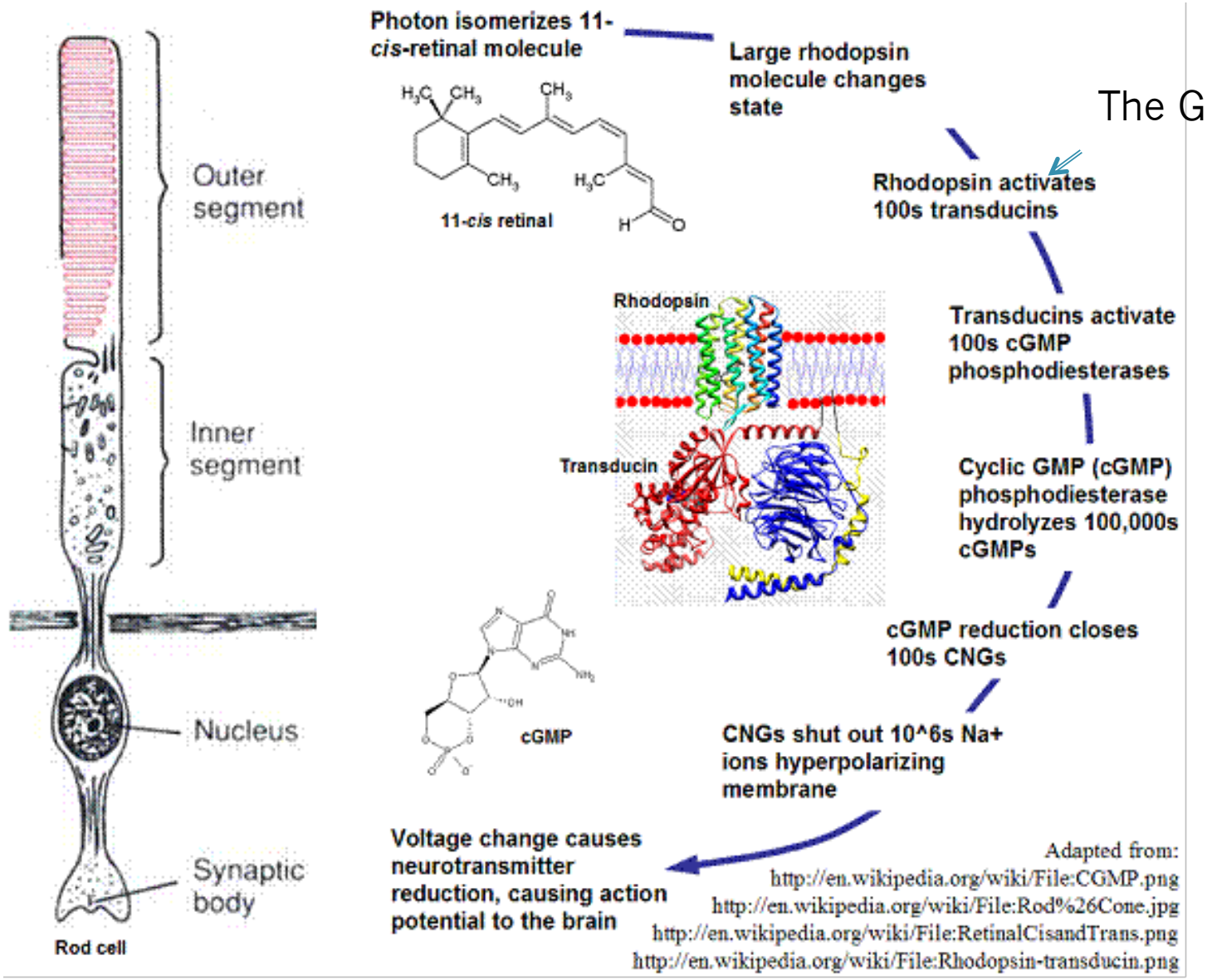
↕

SIGNAL AMPLIFICATION

From light to neural signals



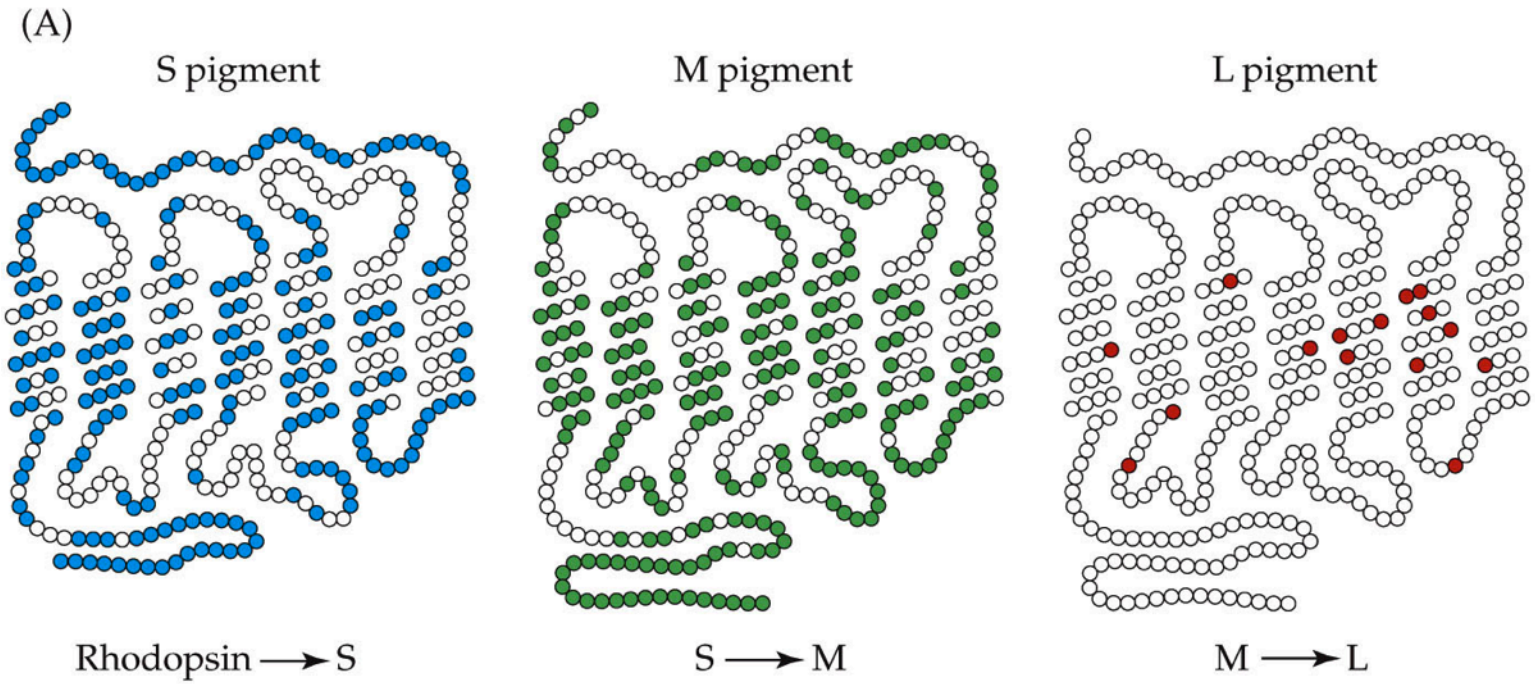
Converting light to action potentials



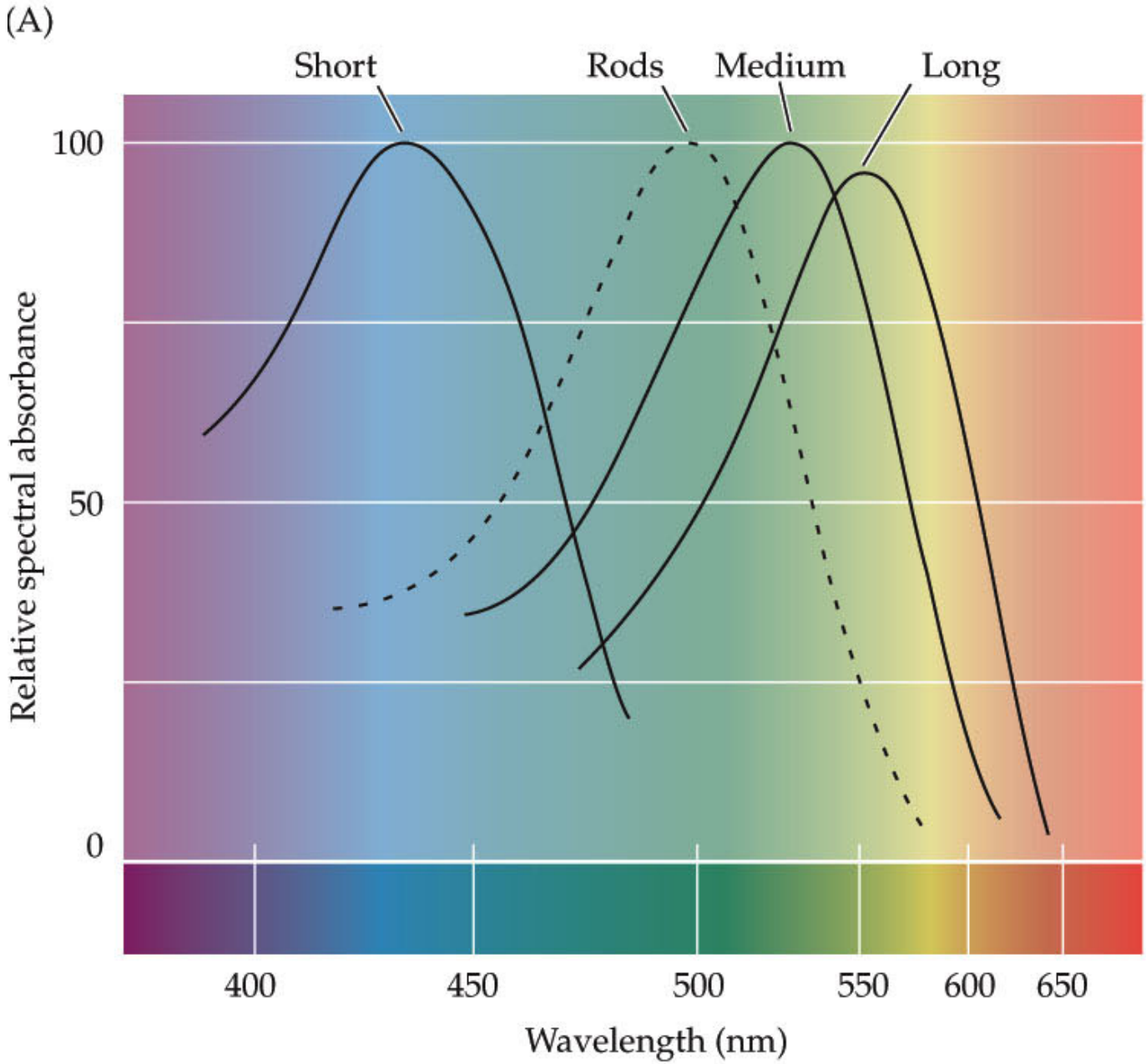
The G protein

TRANSDUCTION

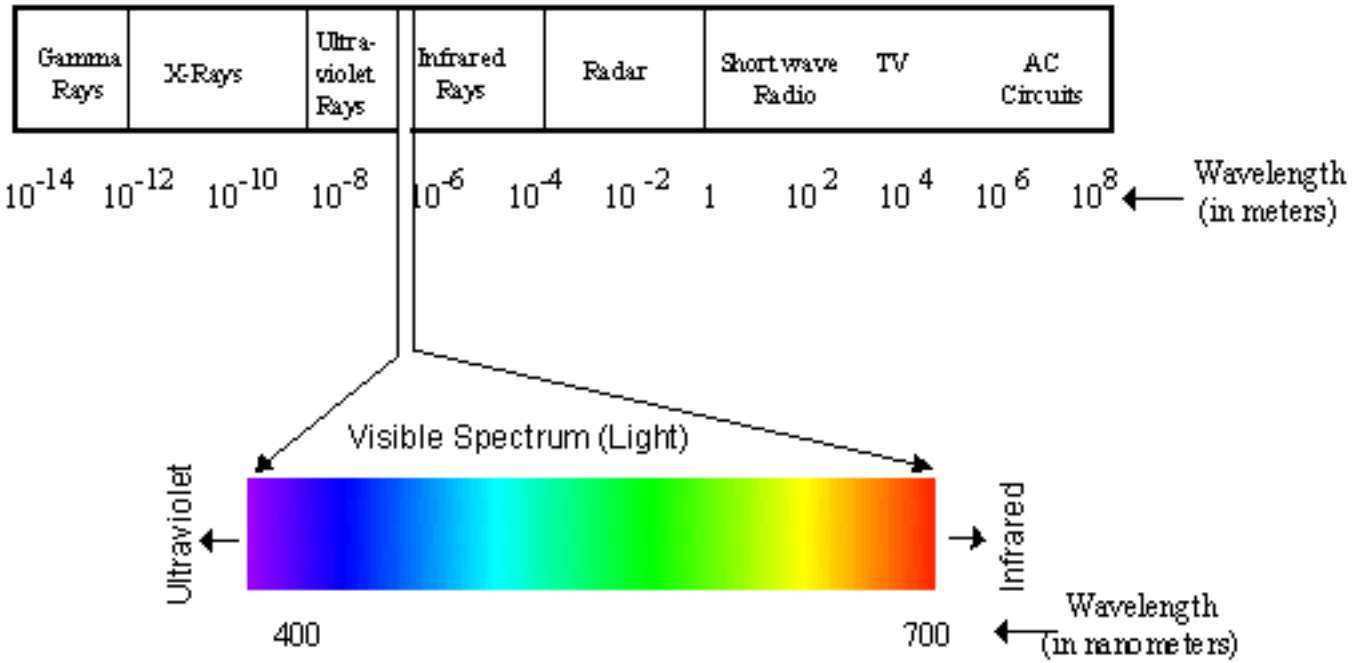
Color vision



Different rhodopsins respond only to photons of specific wavelenghts

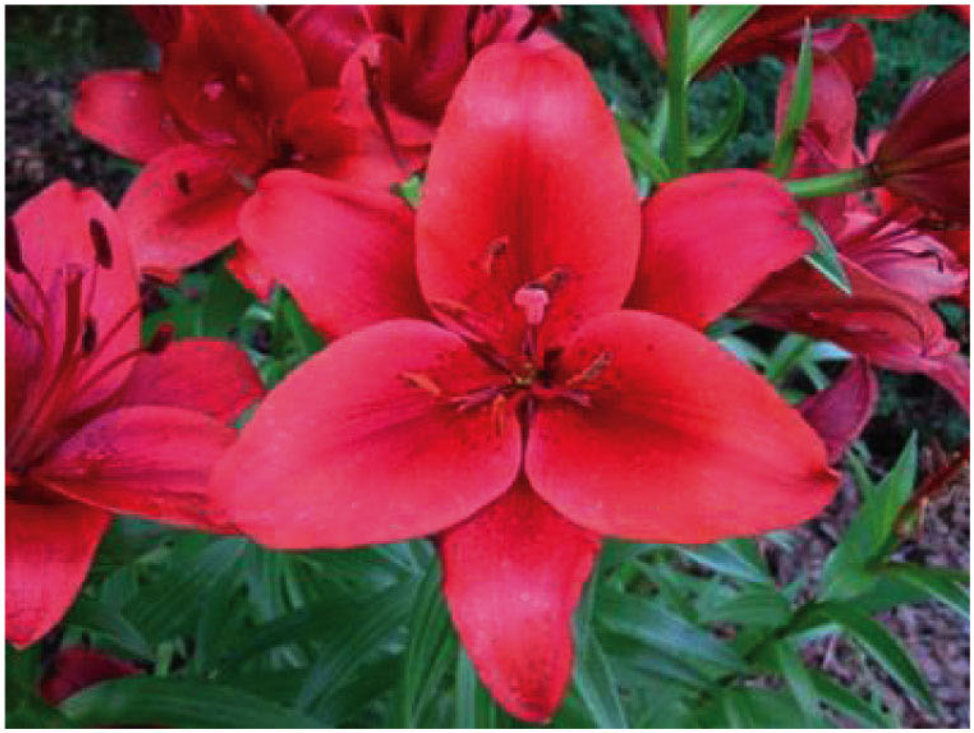

(A)
Short
Rods
Medium
Long
100
50
0
Relative spectral absorbance
400
450
500
550
600
650
Wavelength (nm)

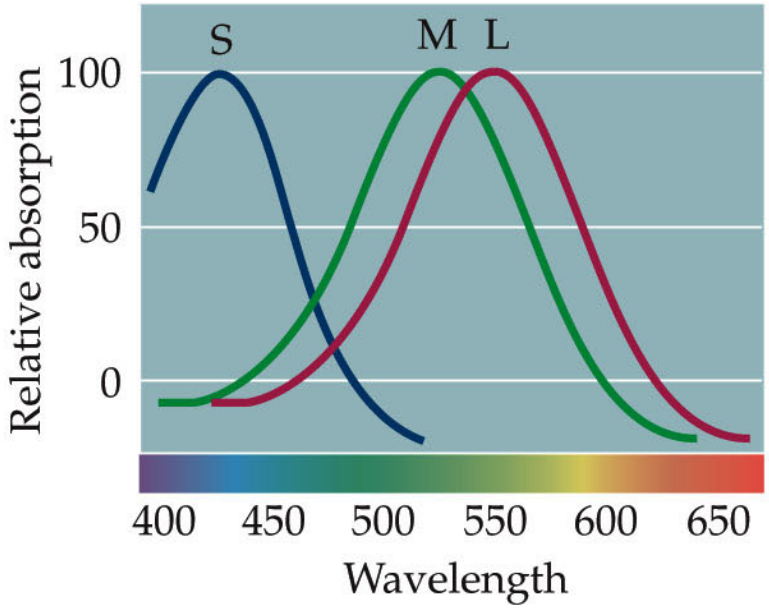
Using these rhodopsins, we can only detect light within the visible spectrum



Light-sensitive proteins called opsins trigger a response when photons of a specific wavelength contact them

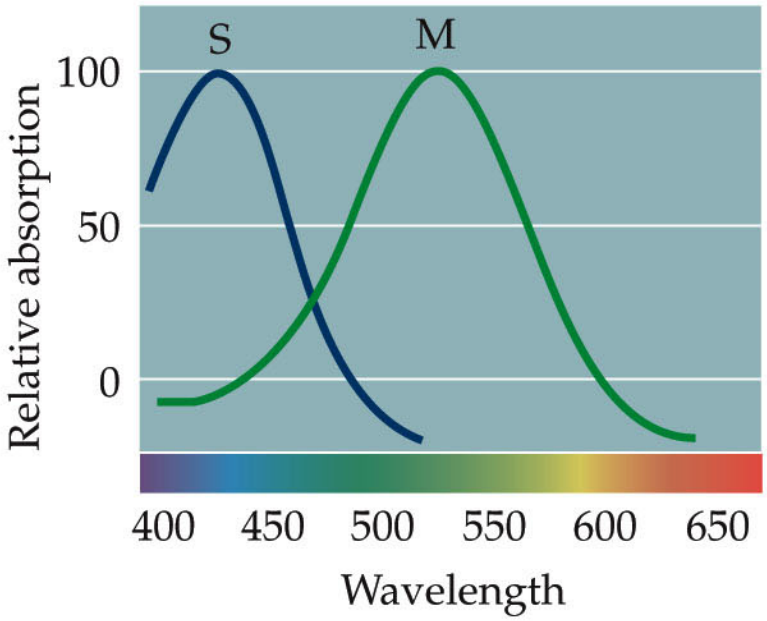
(A) Normal (trichromat)





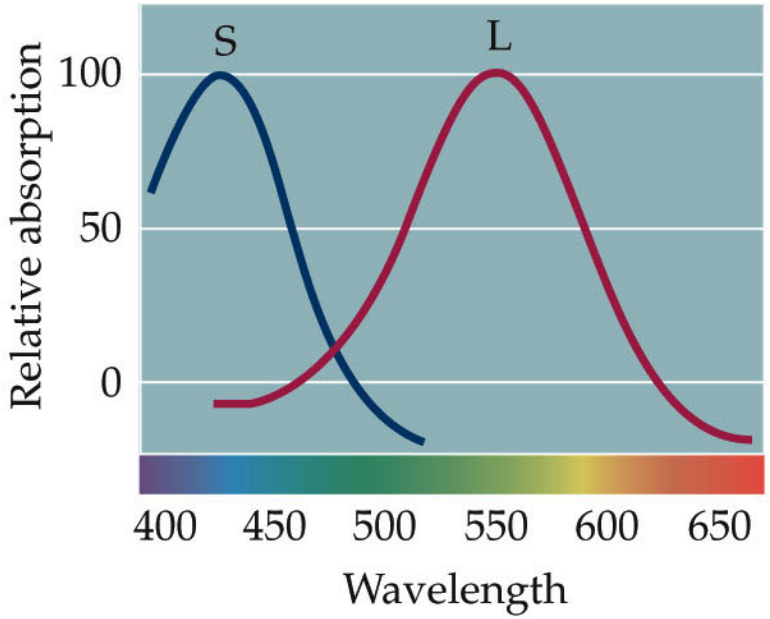
***NEUROSCIENCE, Fourth Edition,* Figure 11.15 (Part 1)**

(B) Protanopia



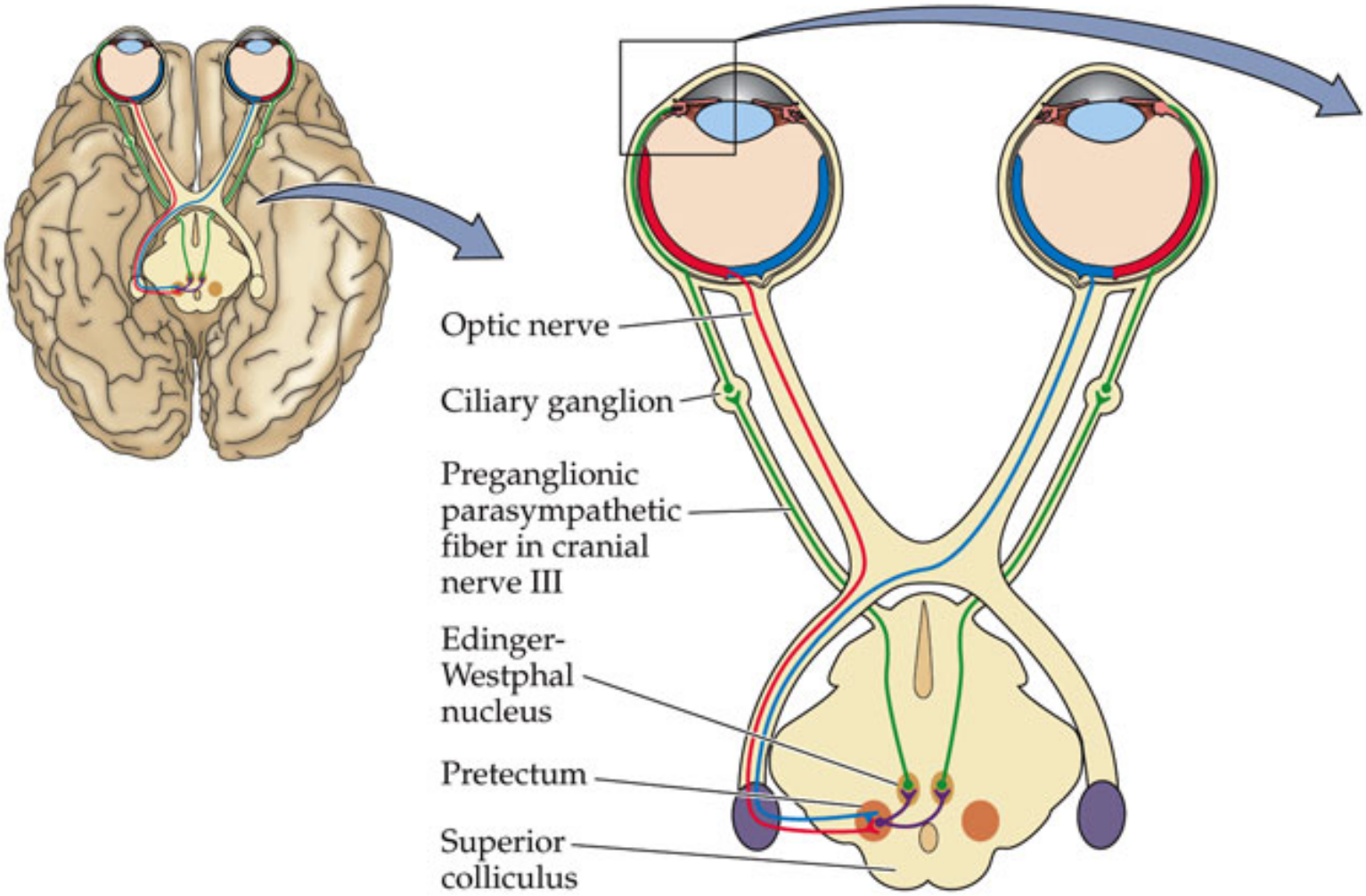
***NEUROSCIENCE, Fourth Edition,* Figure 11.15 (Part 2)**

(C) Deuteranopia



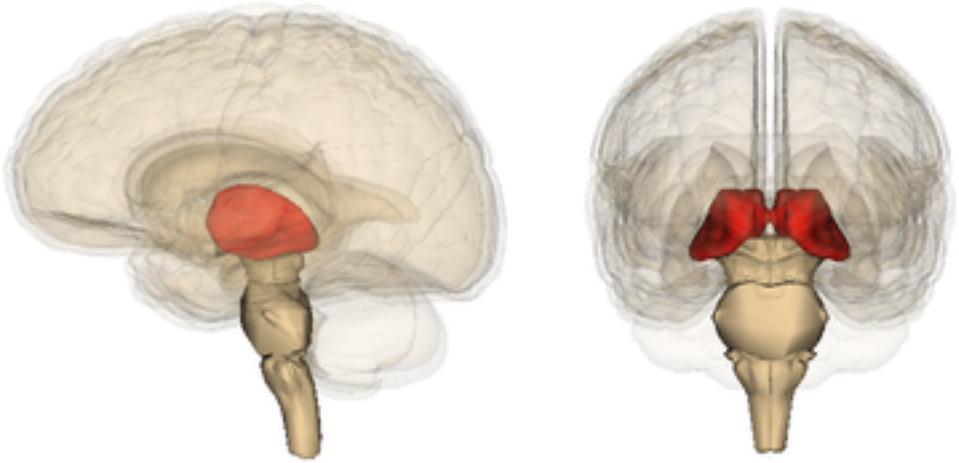
***NEUROSCIENCE, Fourth Edition,* Figure 11.15 (Part 3)**

But we don't 'see' with the eye alone



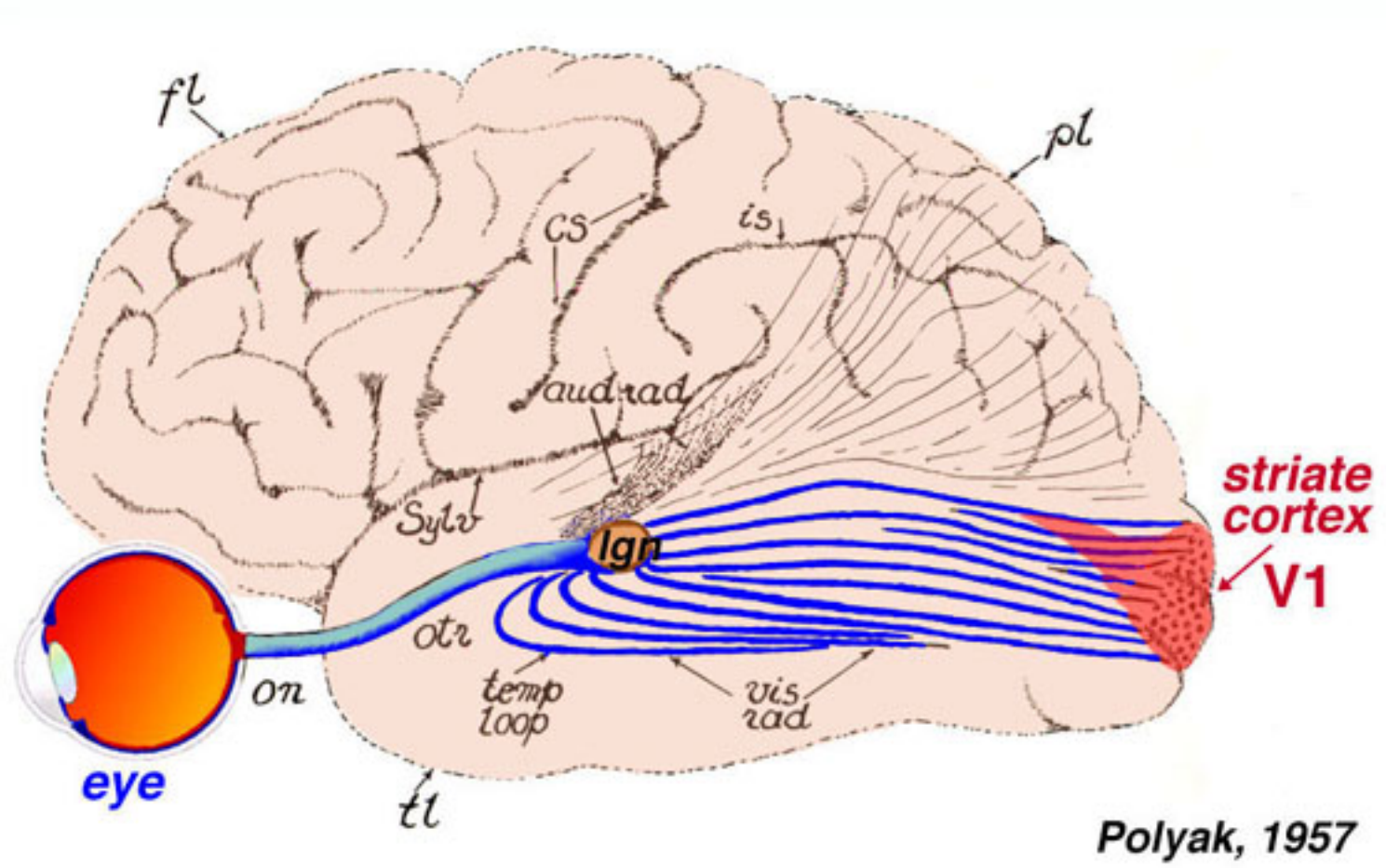
NEUROSCIENCE, Fourth Edition, Figure 12.2 (Part 1)

The thalamus: the relay station of the brain



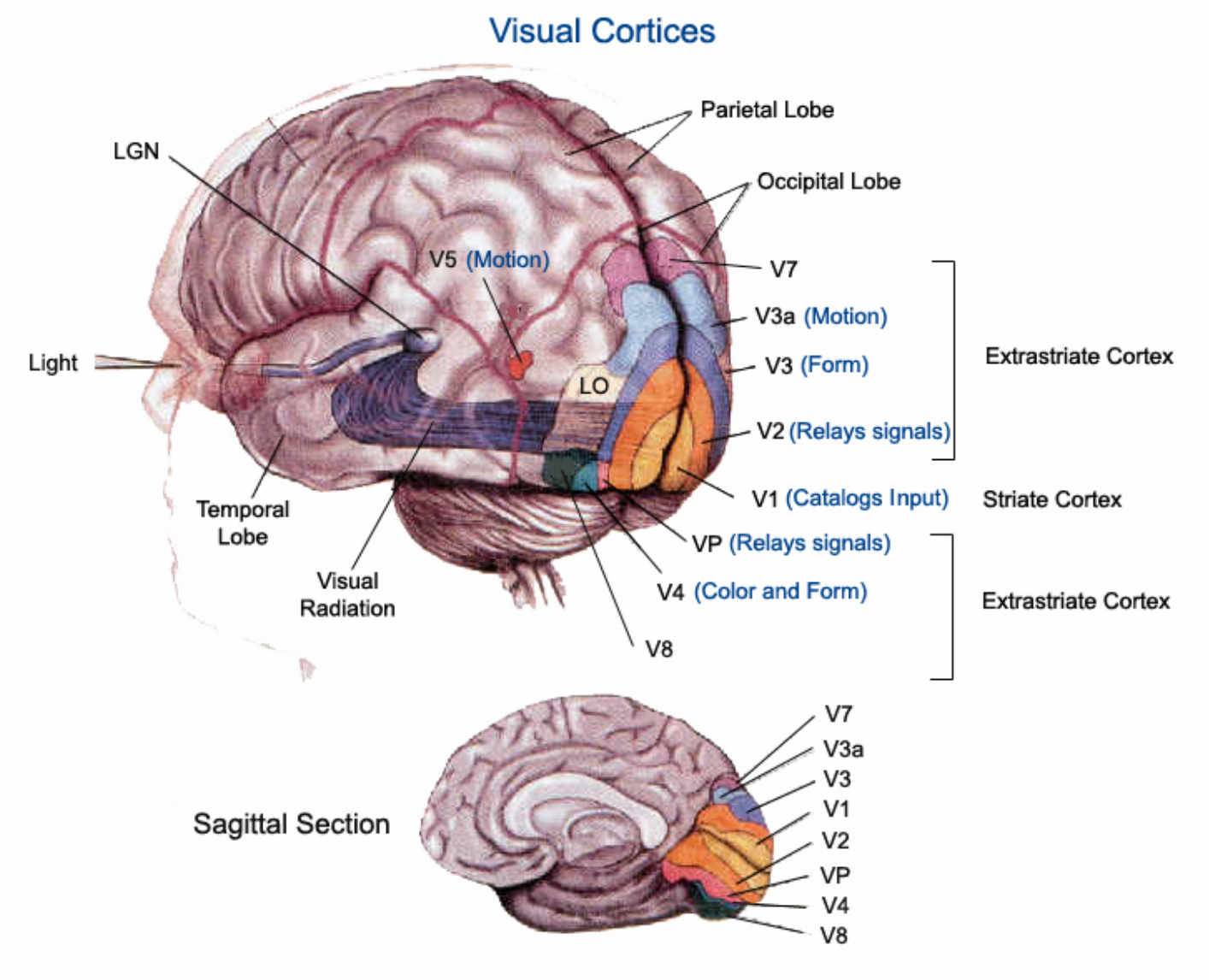
Sensory information comes in from the periphery and passes through the thalamus

After the thalamus

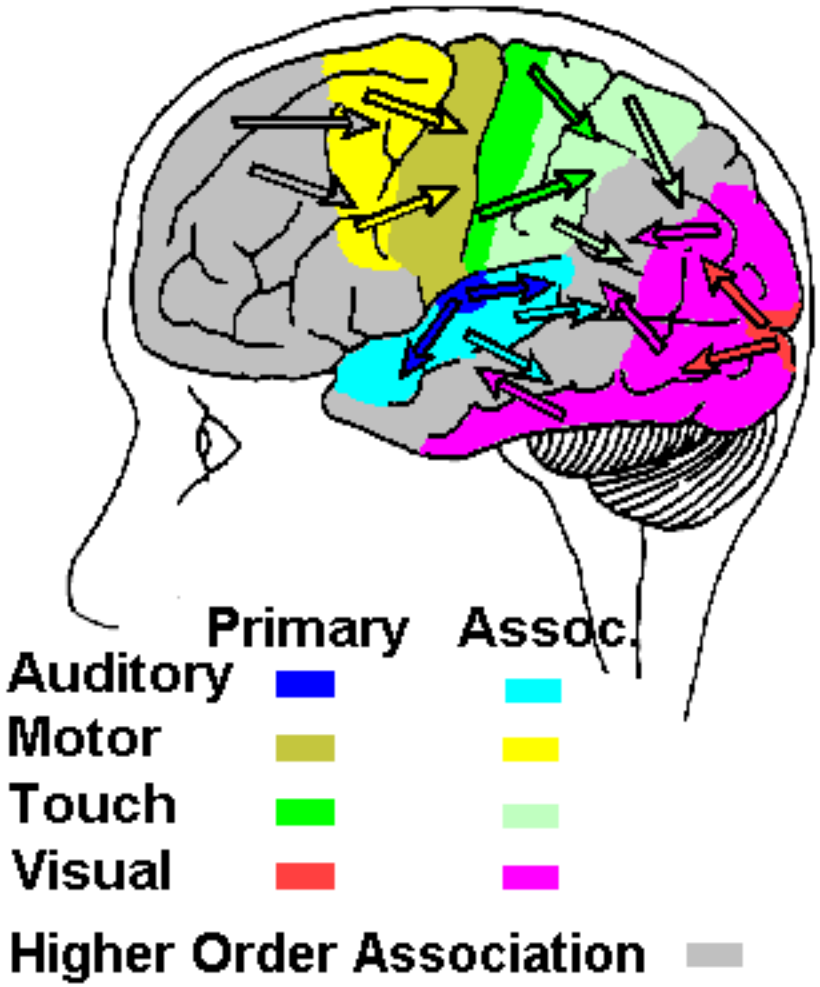


Synaptic information is sent to the primary visual cortex

The visual cortex



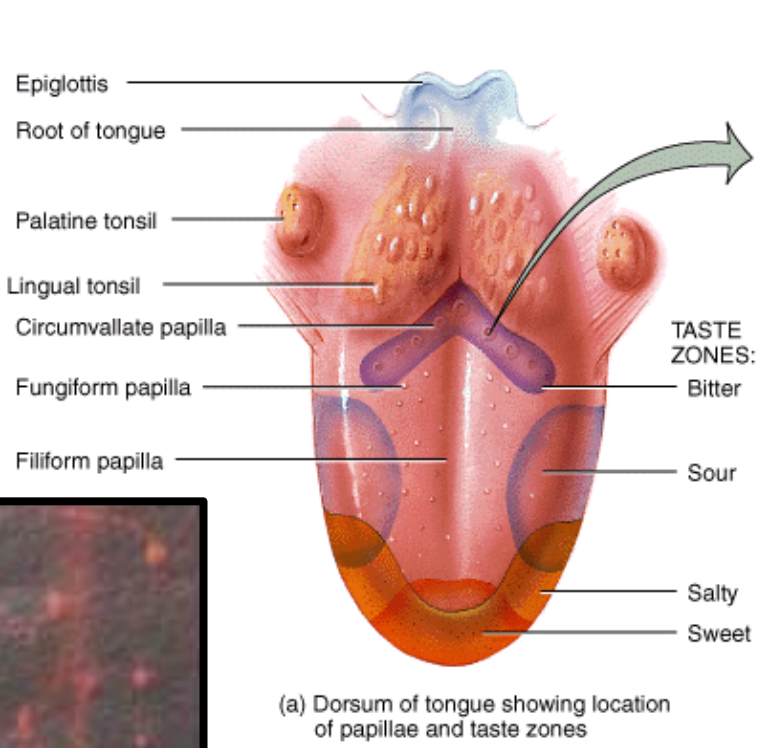
Other sensory cortical areas



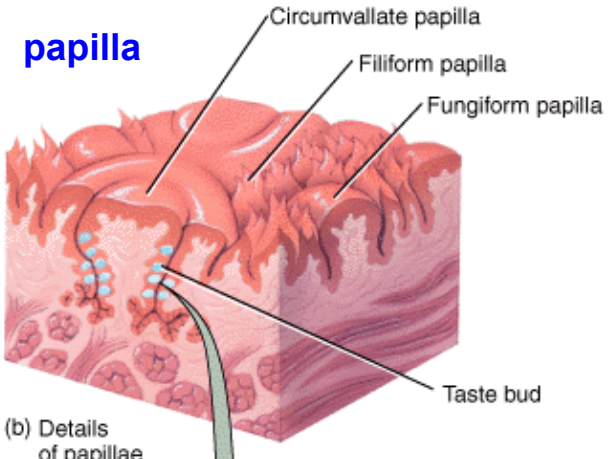
TED talk vision

Taste
(gustation)

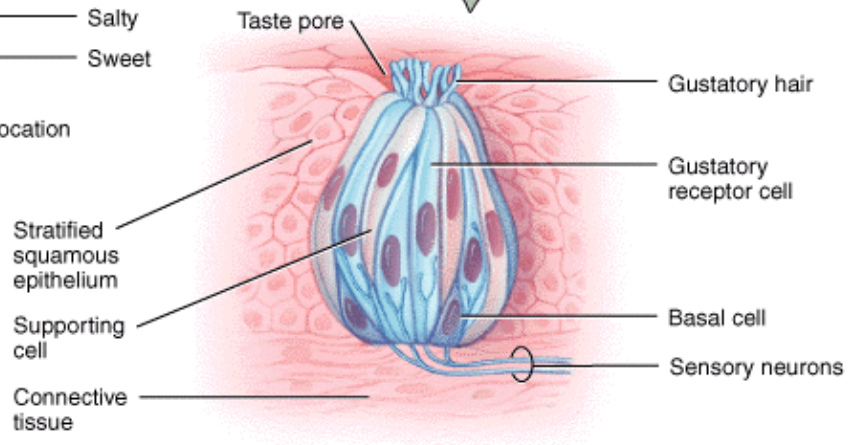
Taste (gustation)



(a) Dorsum of tongue showing location of papillae and taste zones

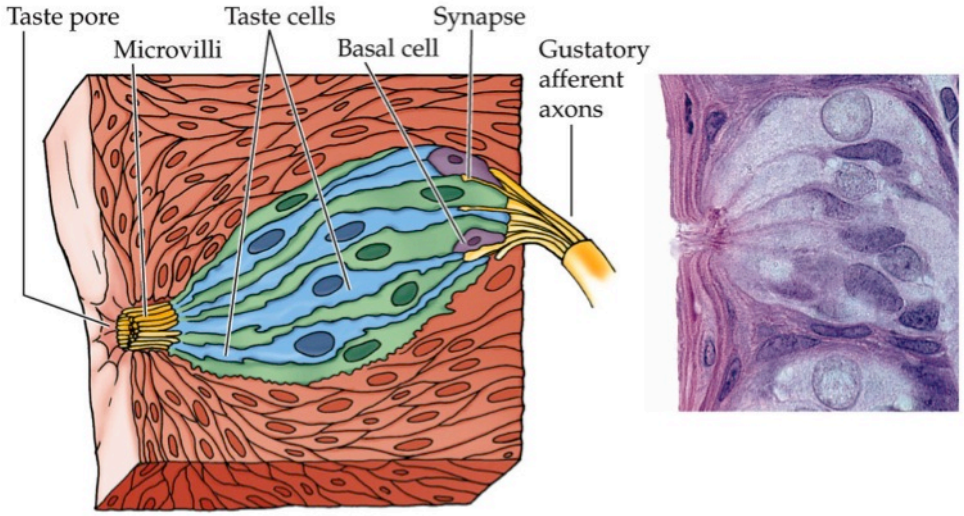


(b) Details of papillae



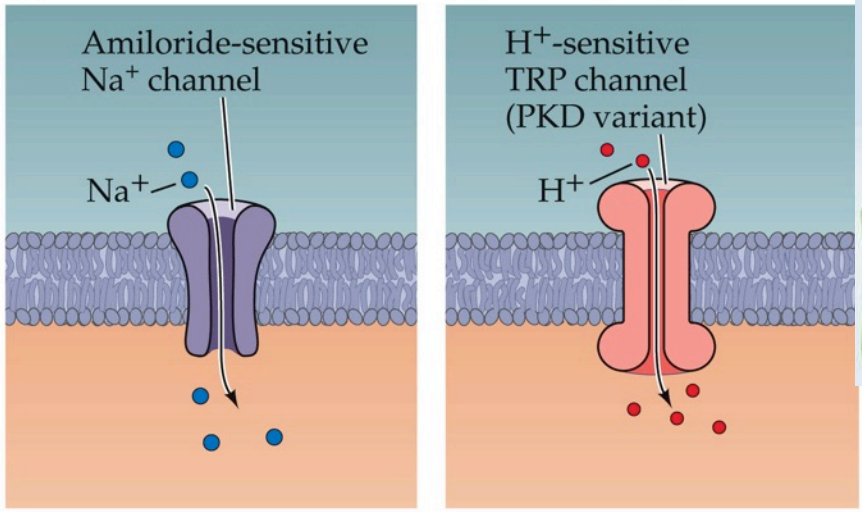
(c) Structure of a taste bud

Taste Bud


Taste pore
Microvilli
Taste cells
Basal cell
Synapse
Gustatory afferent axons

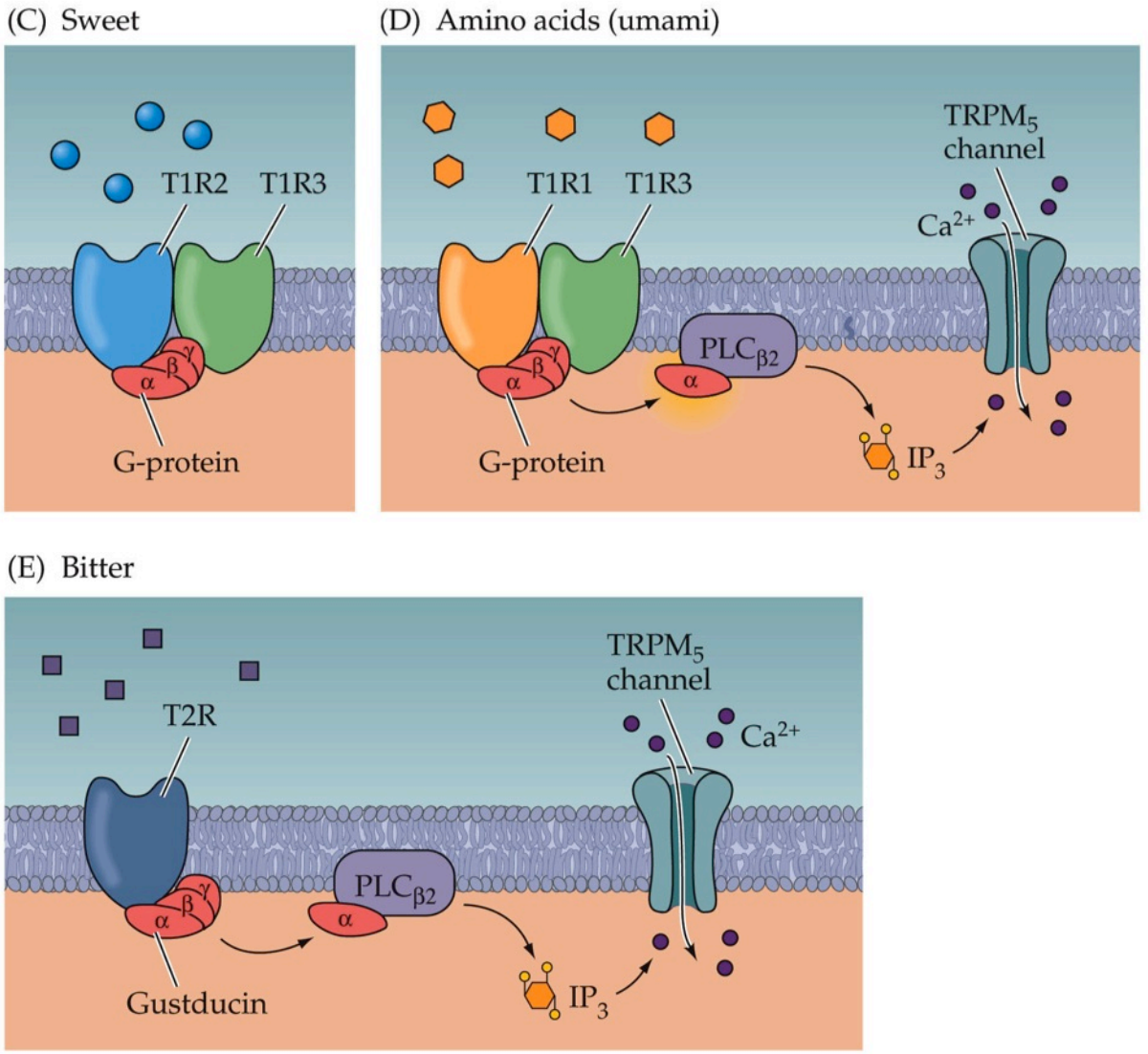
Taste Receptors

ion channels

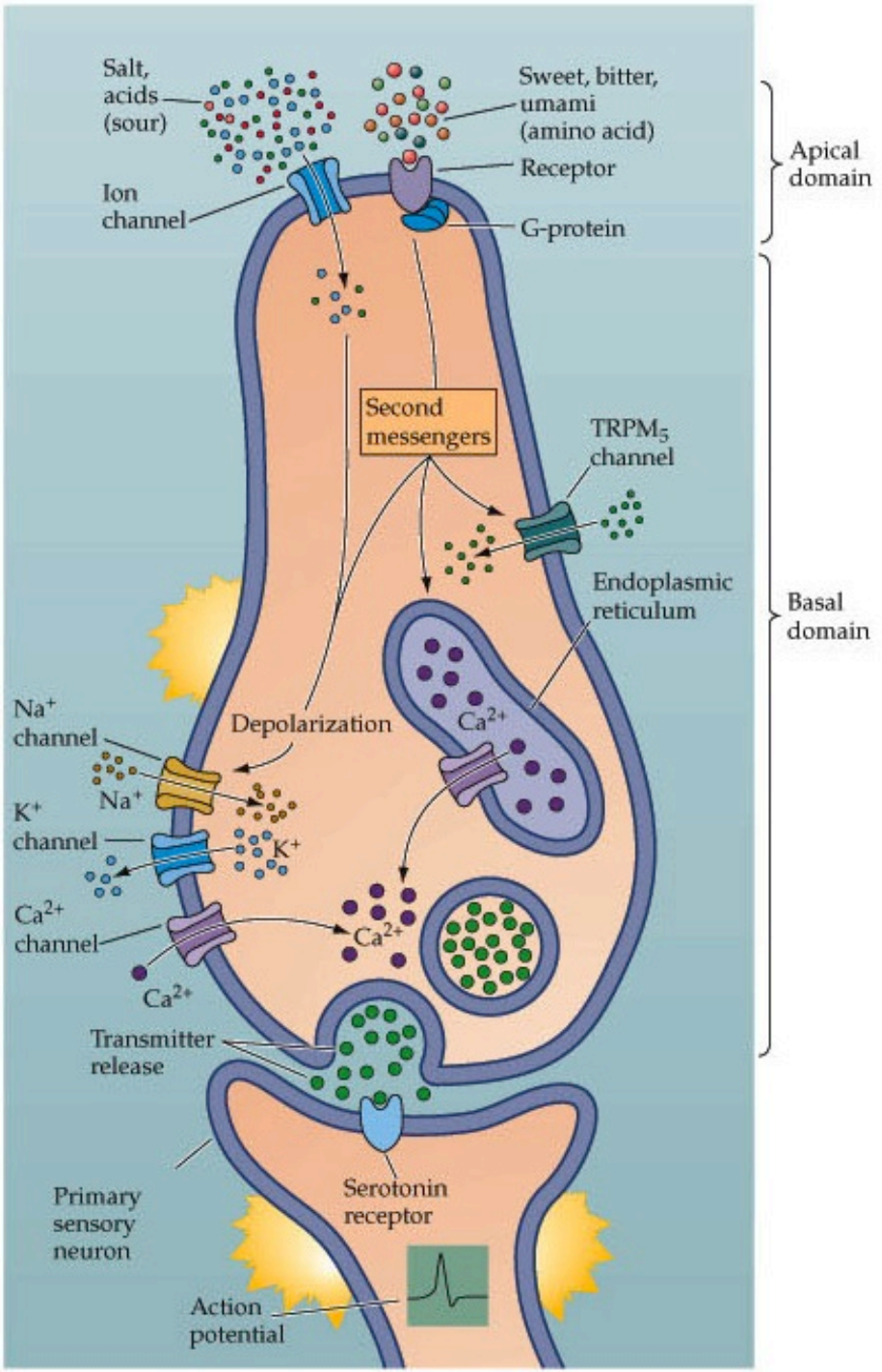


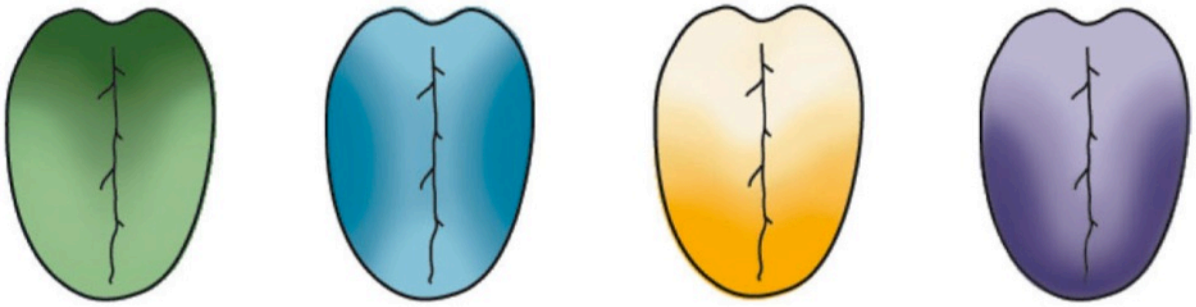
Taste Receptors

GPCRs

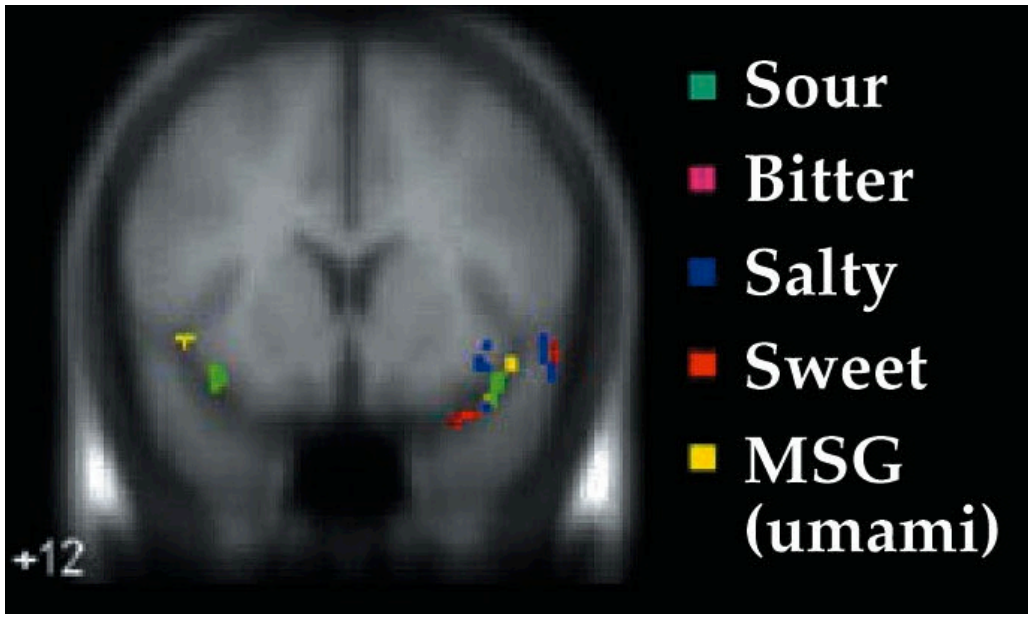


Taste Cell


Salt, acids (sour)
Sweet, bitter, umami (amino acid)
Receptor
Ion channel
G-protein
Apical domain
Second messengers
TRPM5 channel
Endoplasmic reticulum
Basal domain
Na+ channel
Depolarization
Ca2+
Na+
K+ channel
K+
Ca2+ channel
Ca2+
Ca2+
Transmitter release
Primary sensory neuron
Serotonin receptor
Action potential



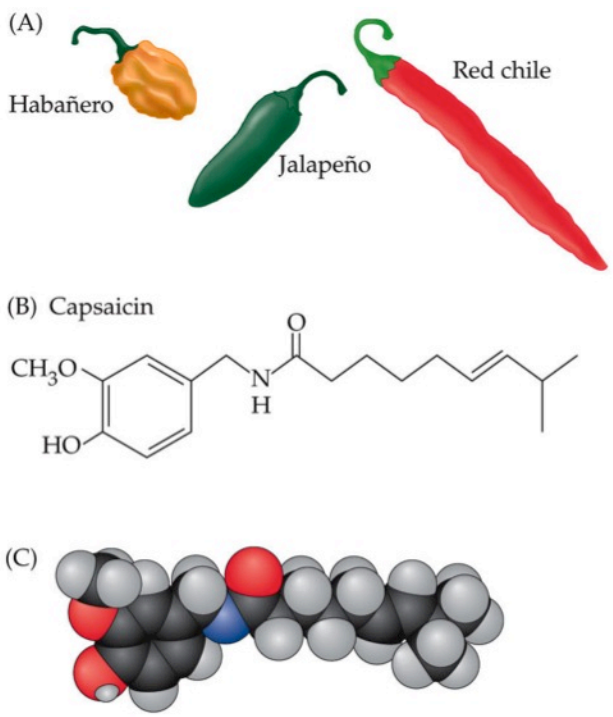
Bitter Sour Sweet/ umami Salty

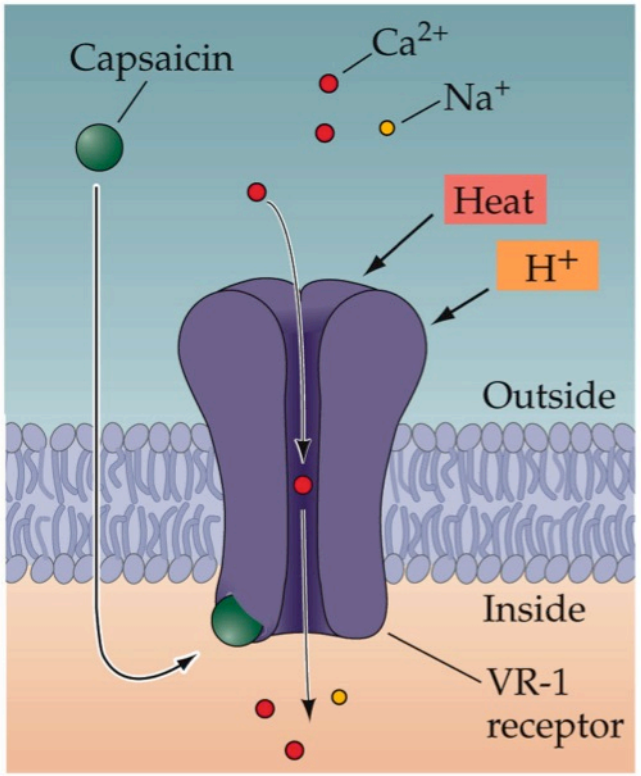


SCOVILLE CHILE HEAT CHART

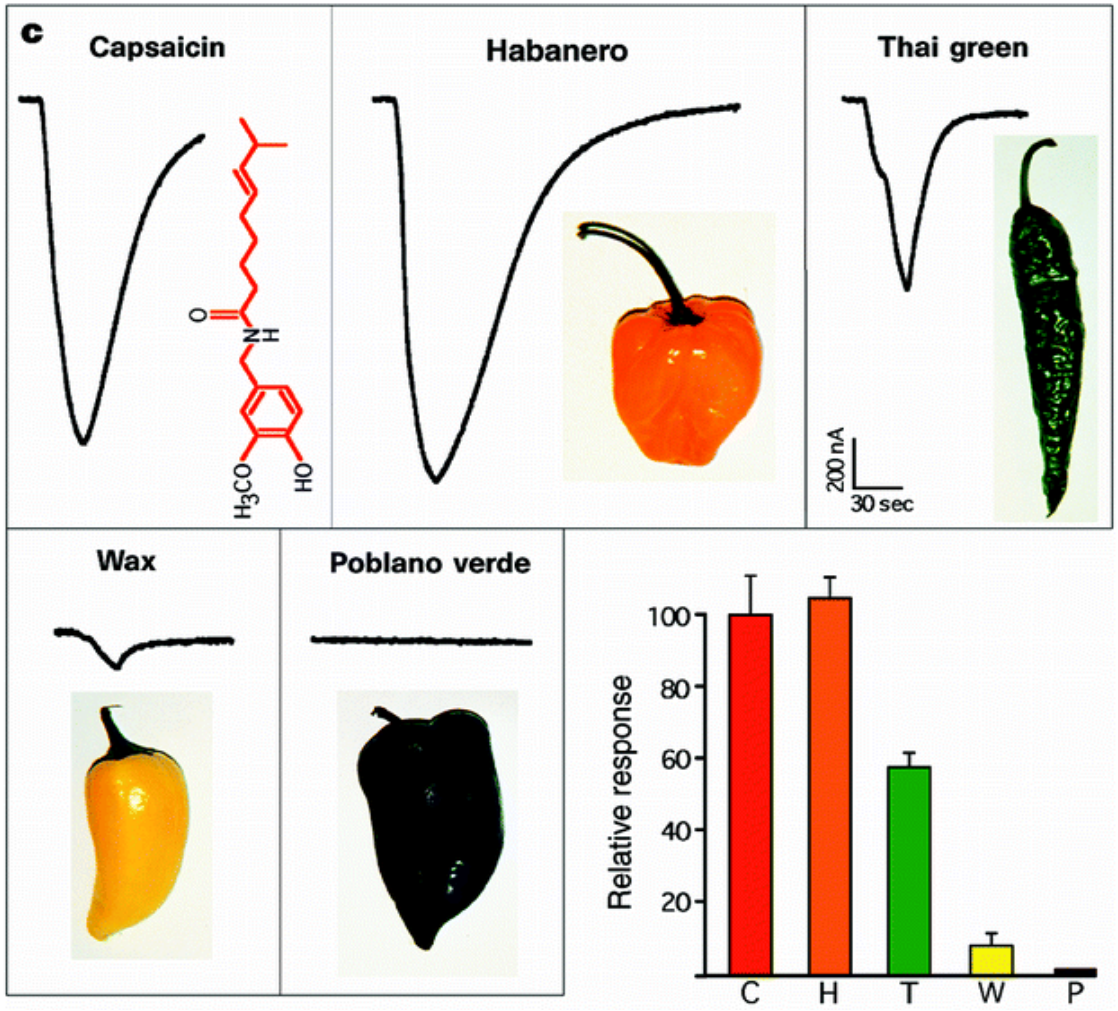
SCOVILLE HEAT UNITS	TYPES OF PEPPERS
15,000,000	Pure Capsaician
2,000,000-5,300,000	U.S. Grade Pepper Spray
1,000,000	Bhut Jolokia
577,000	Red Savina
200,000-350,000	Habanero
100,000-250,000	Chiltepin
30,000-50,000	Cayenne
15,000-30,000	Arbol
12,000-30,000	Manzano
8,000-23,000	Serrano
5,000-8,000	Yellow Hot
3,500-8,000	Jalepeño Pepper
2,500-4,000	Guajillo
1,500-2,500	Chilaca
1,000-2,500	Pasilla
1,000-2,000	Pablano
500-2,000	Anaheim
500-1,500	Chile Verde
500-1,000	Yellow Genetics
500-750	Red Chile
0	Sweet Bells

Spiciness





TRPV1 Receptor:
noxious heat detector



Pure capsaicin	(C)	16 x 10^{16} Scoville units
Habanero (H)		100,000 - 300,000
Thai green (T)		50,000 - 100,000
Wax (W)		5,000 - 10,000
Poblano verde (P)		1,000 - 1,500

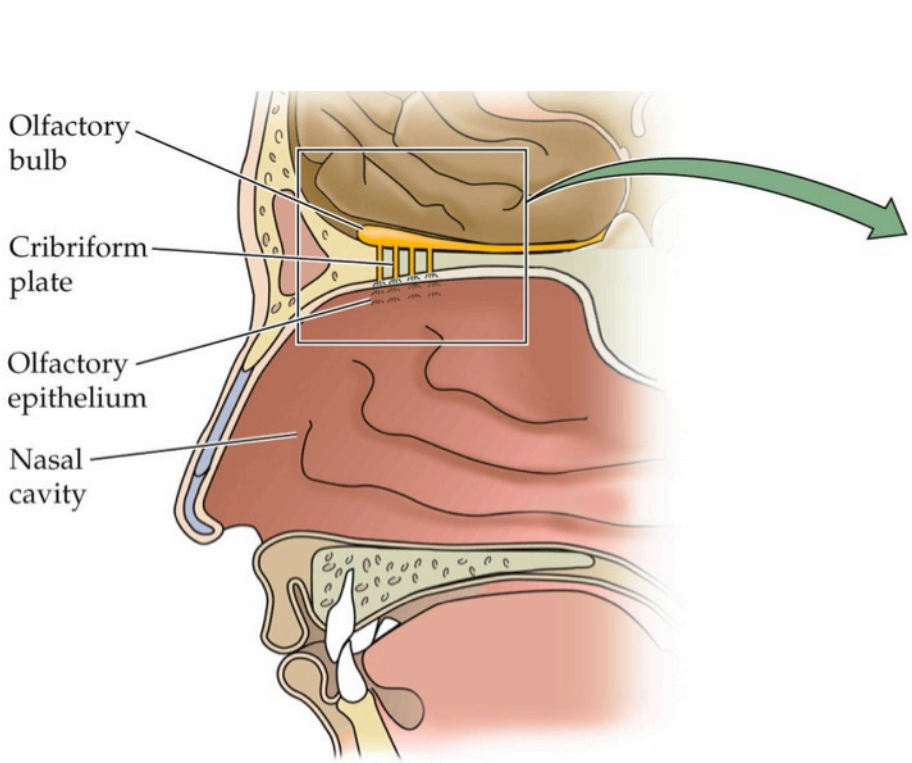
Caterina *et al.* Nature 1997

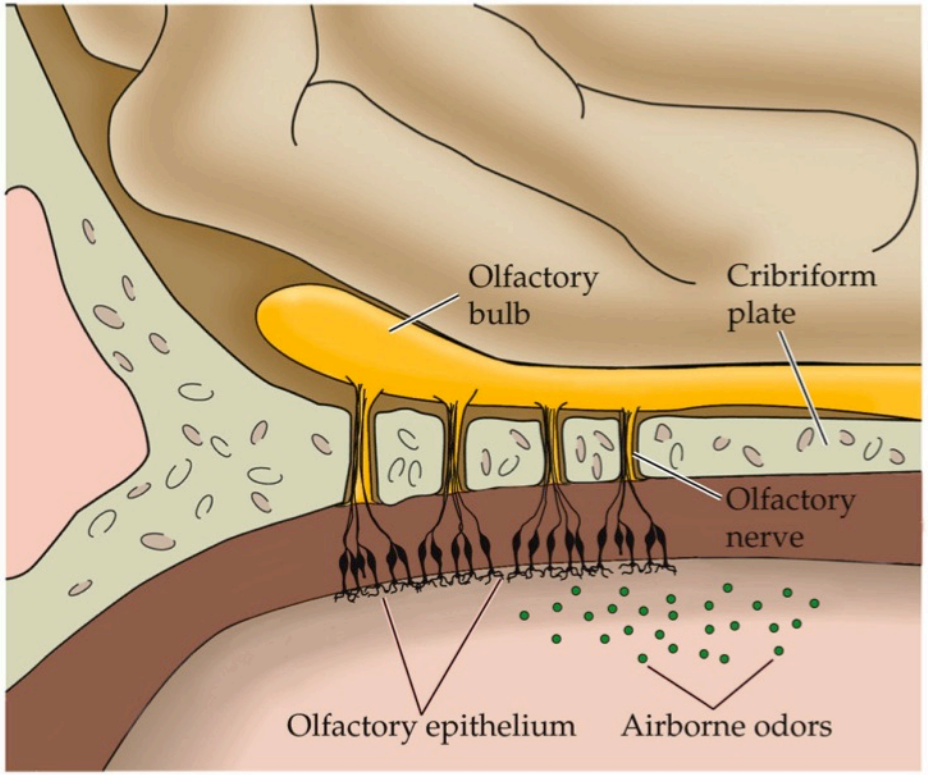
Taste

- Receptor?
- Transduction?
- Specificity/Tuning?

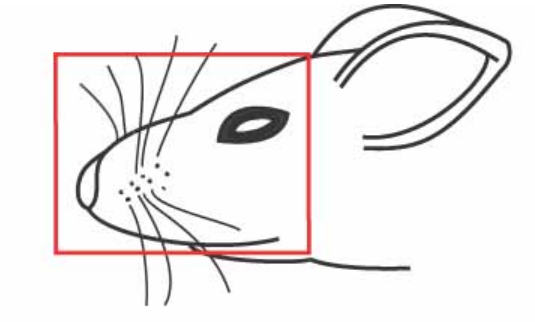
Smell
(olfaction)

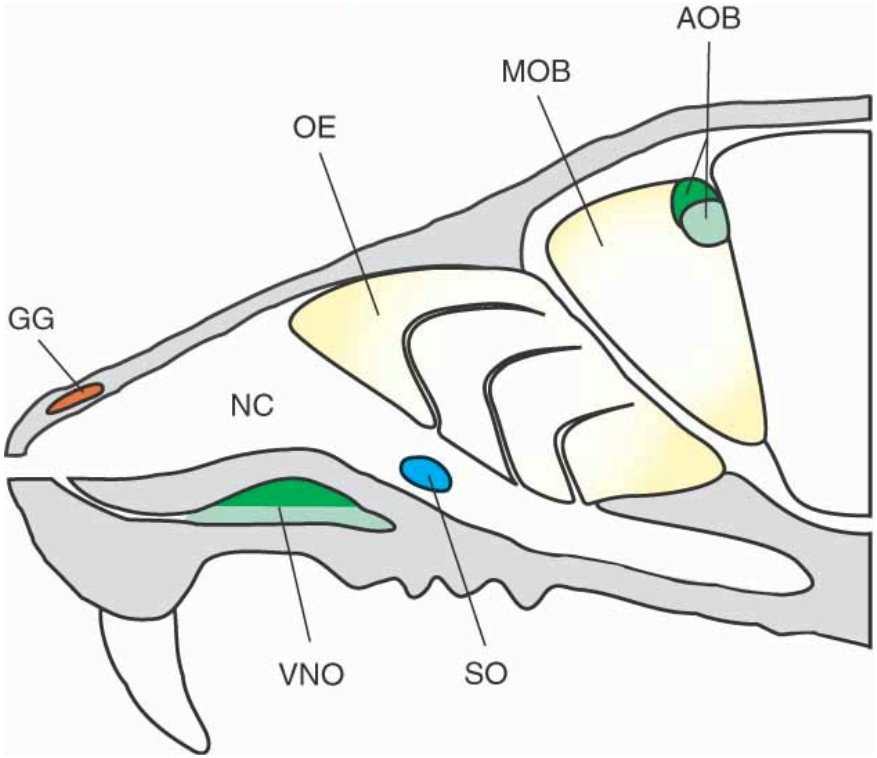
Smell (olfaction)



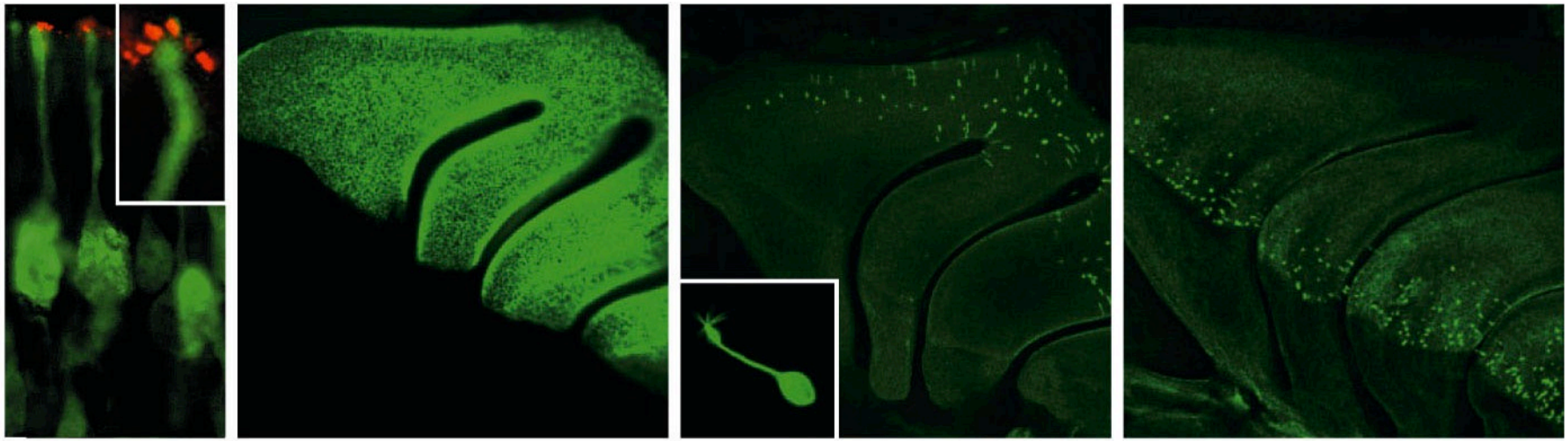


Mouse Olfactory System

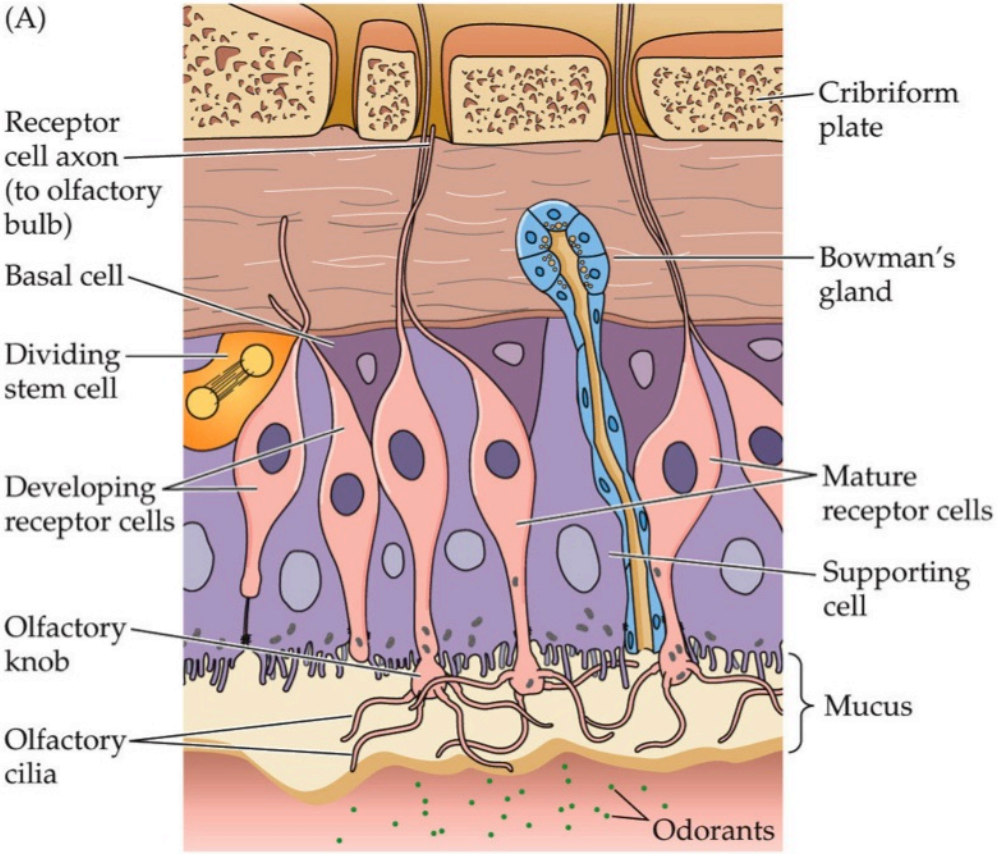




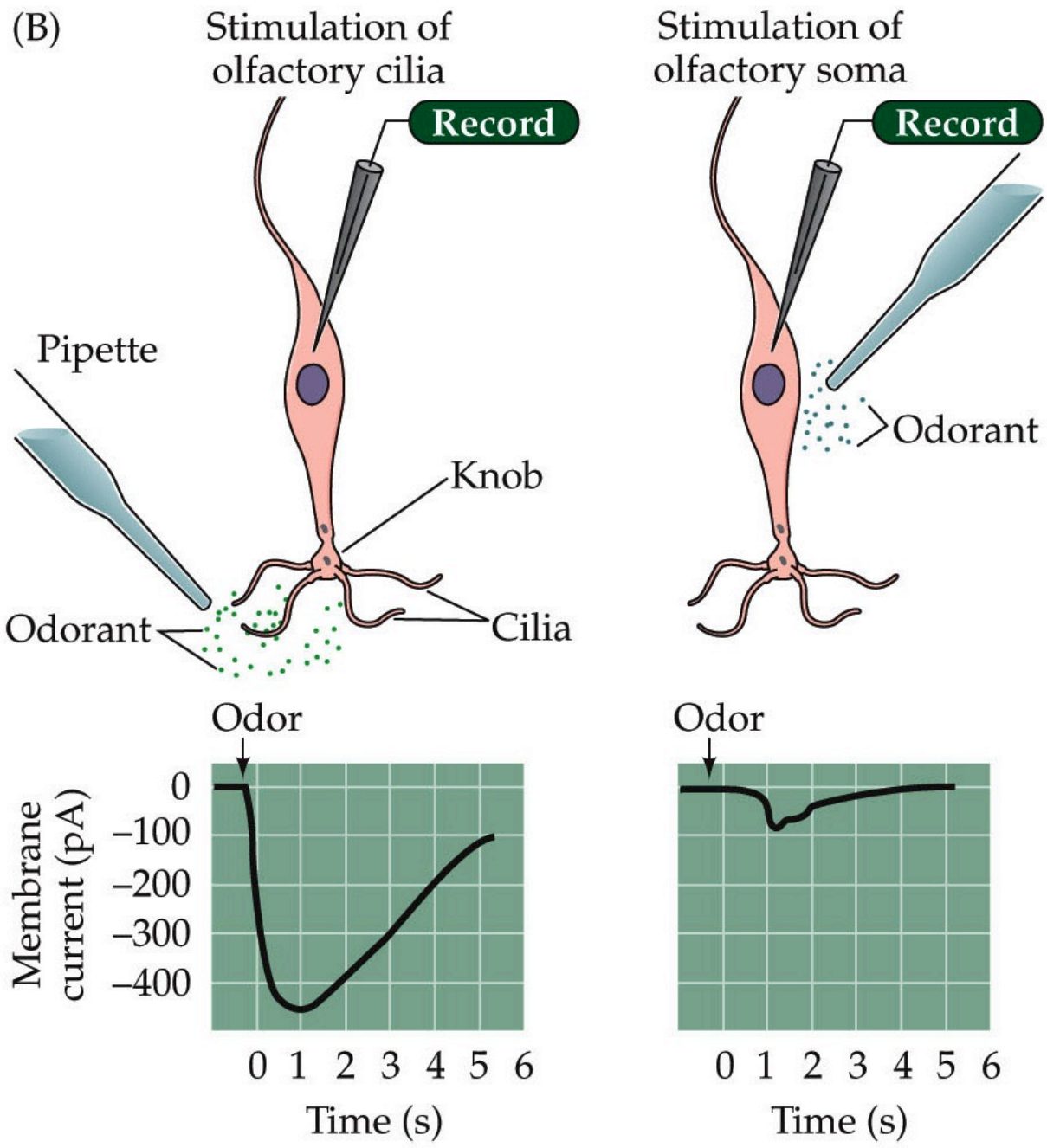
Olfactory Sensory Neurons



Olfactory Epithelium



Olfactory Sensory Neurons

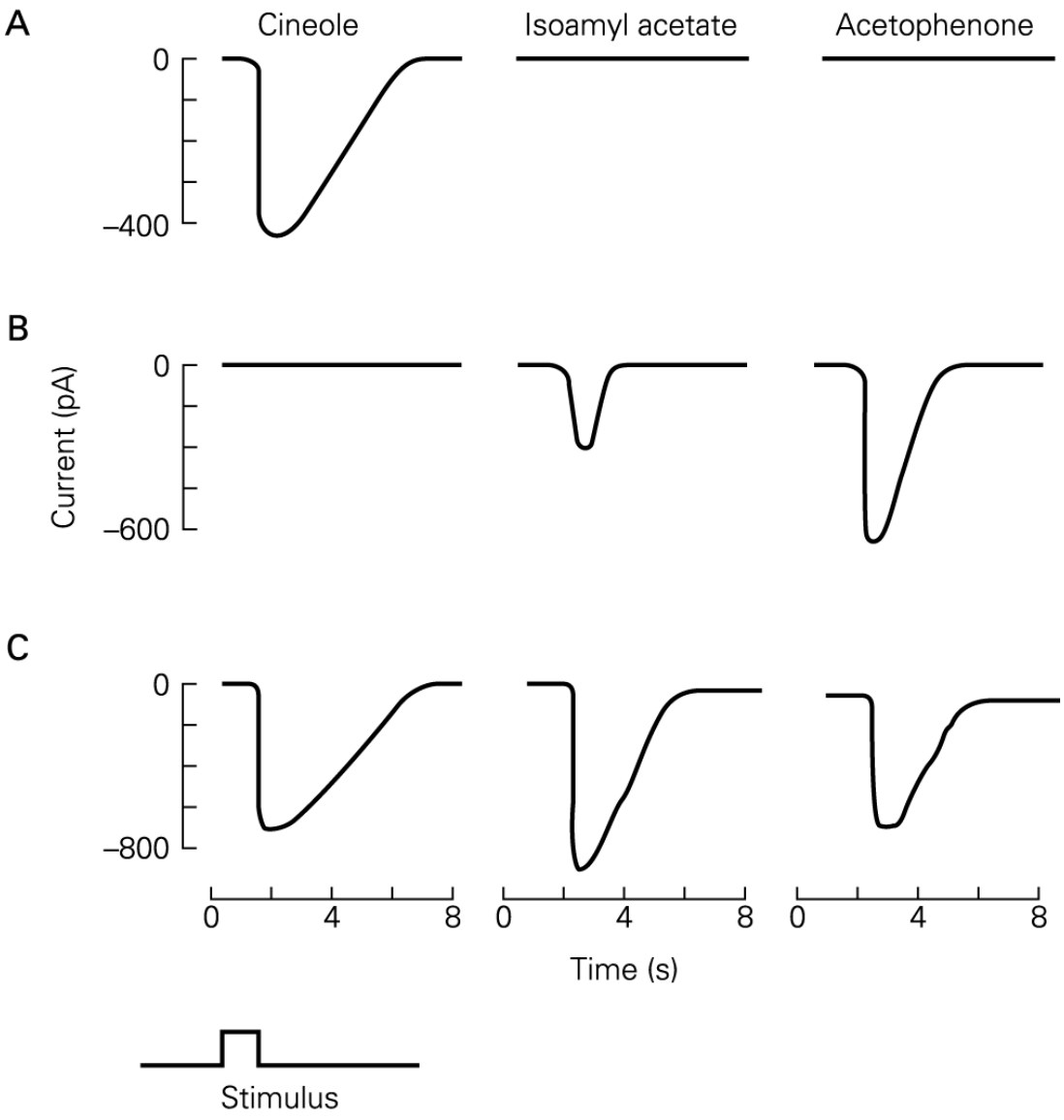


Odor "Tuning" in Olfactory Sensory Neurons

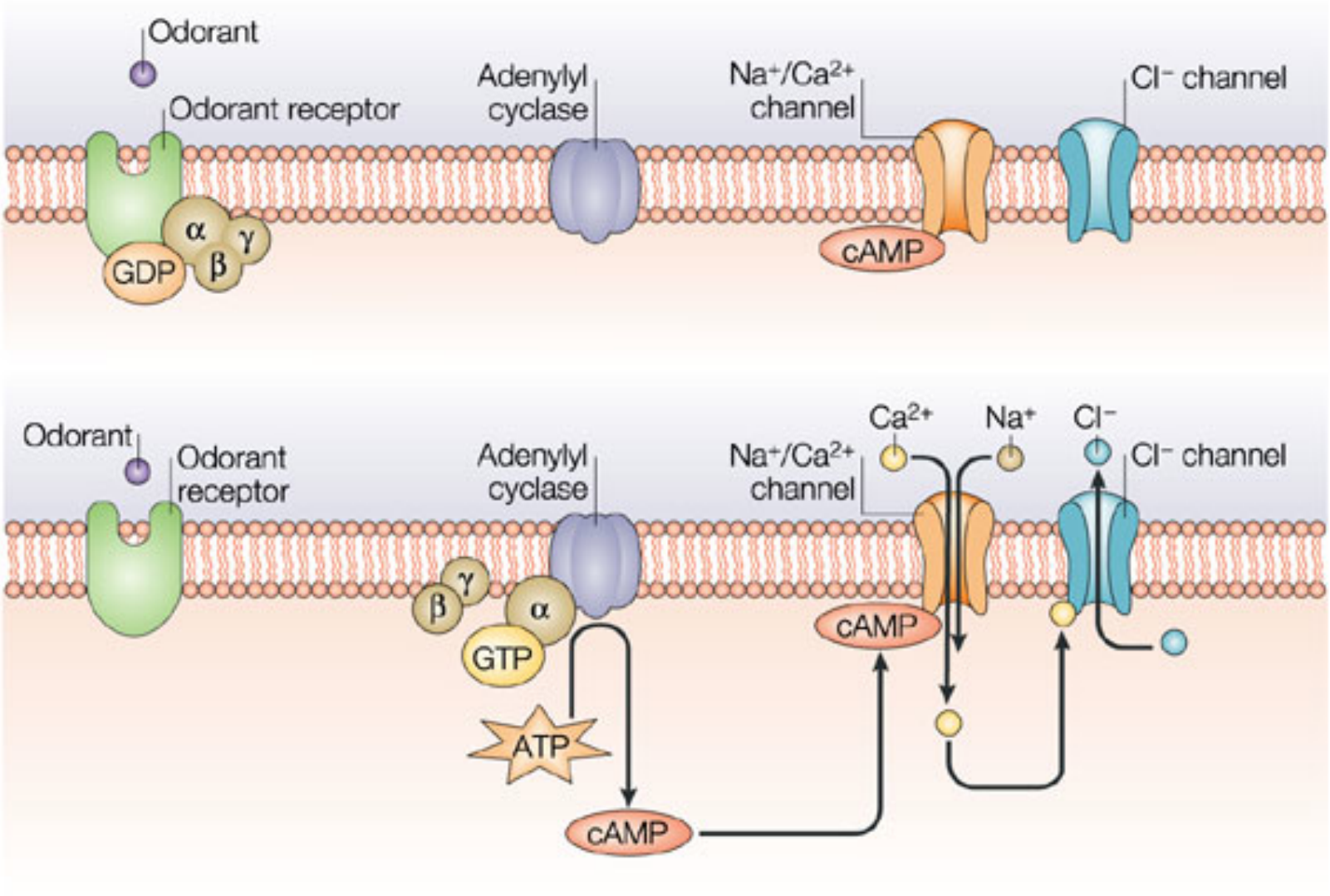
Neuron A

Neuron B

Neuron C

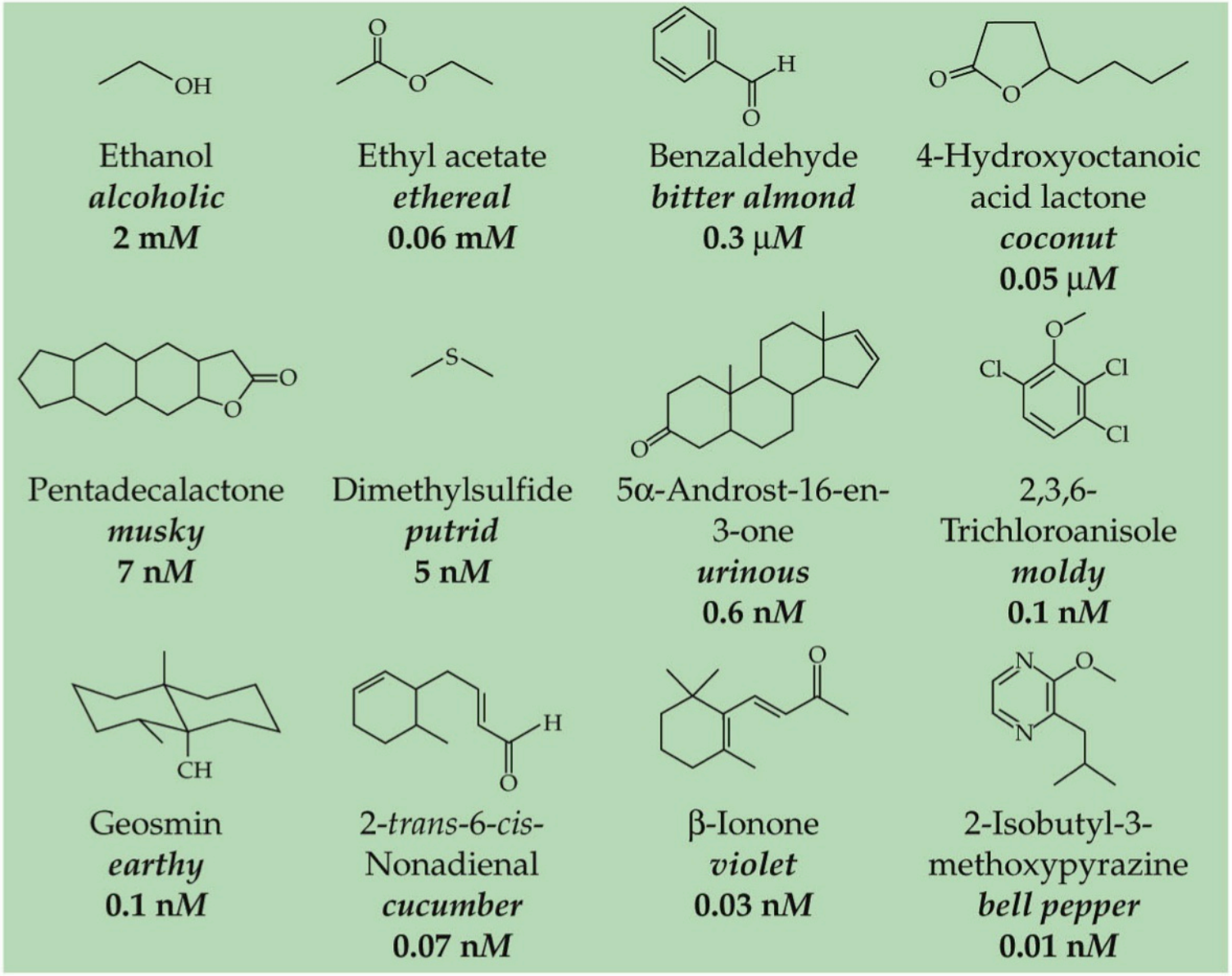


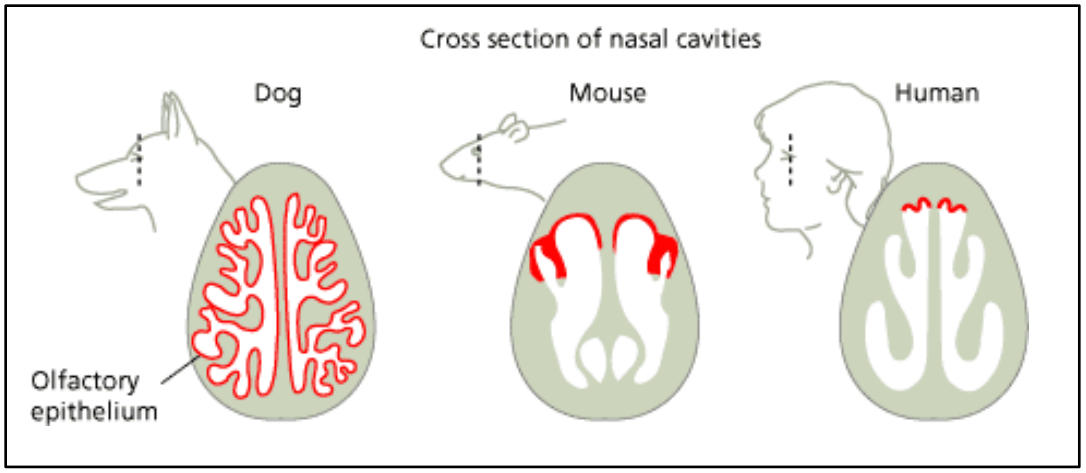
Odorant receptors



Nature Reviews | Neuroscience

Human Odor Thresholds

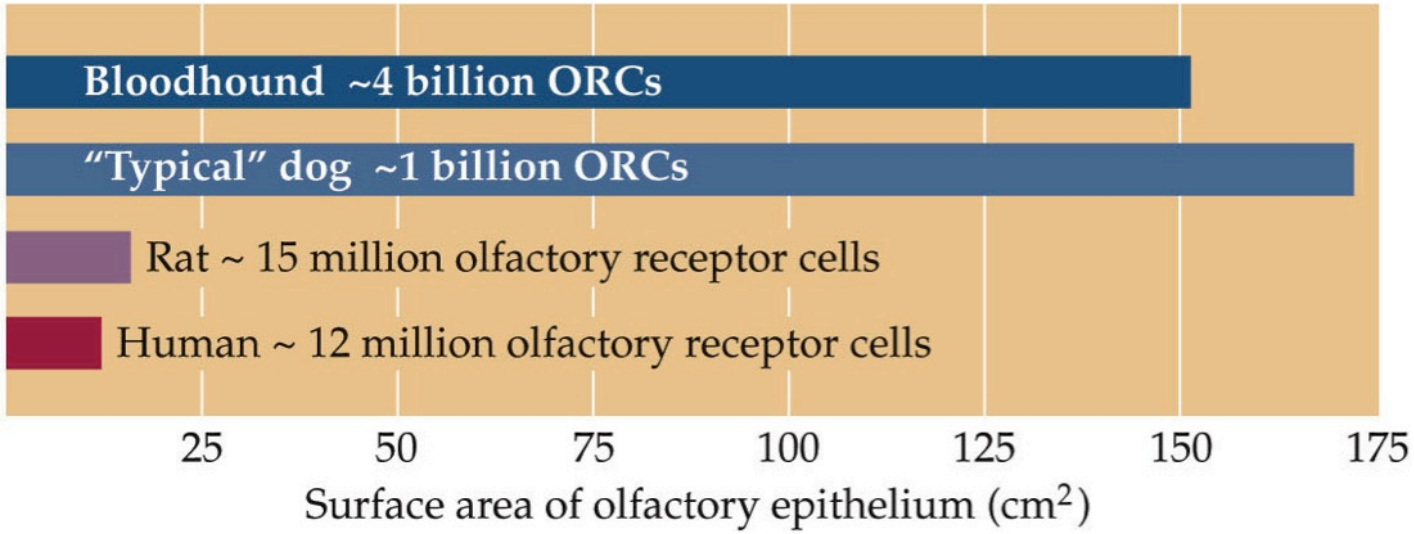


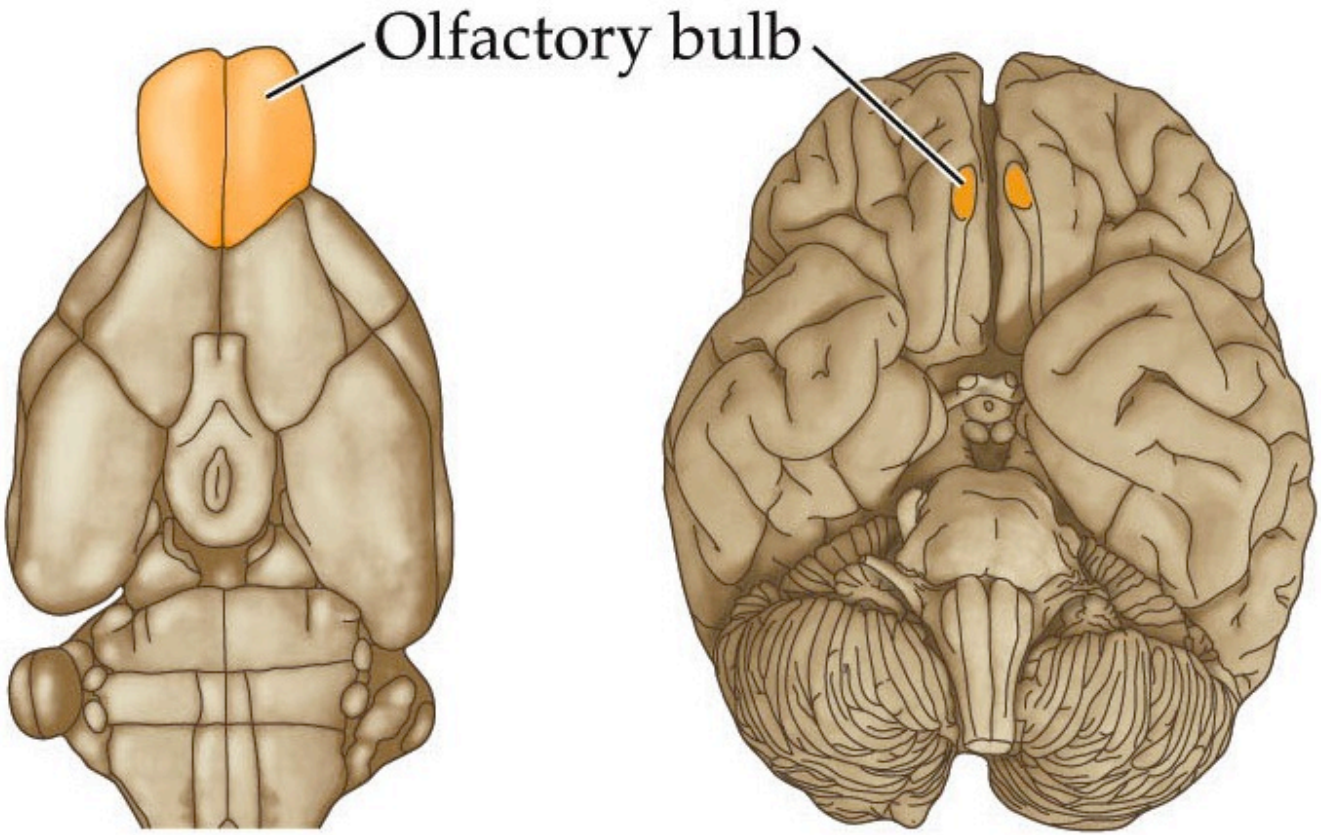


Olfactory receptor genes:

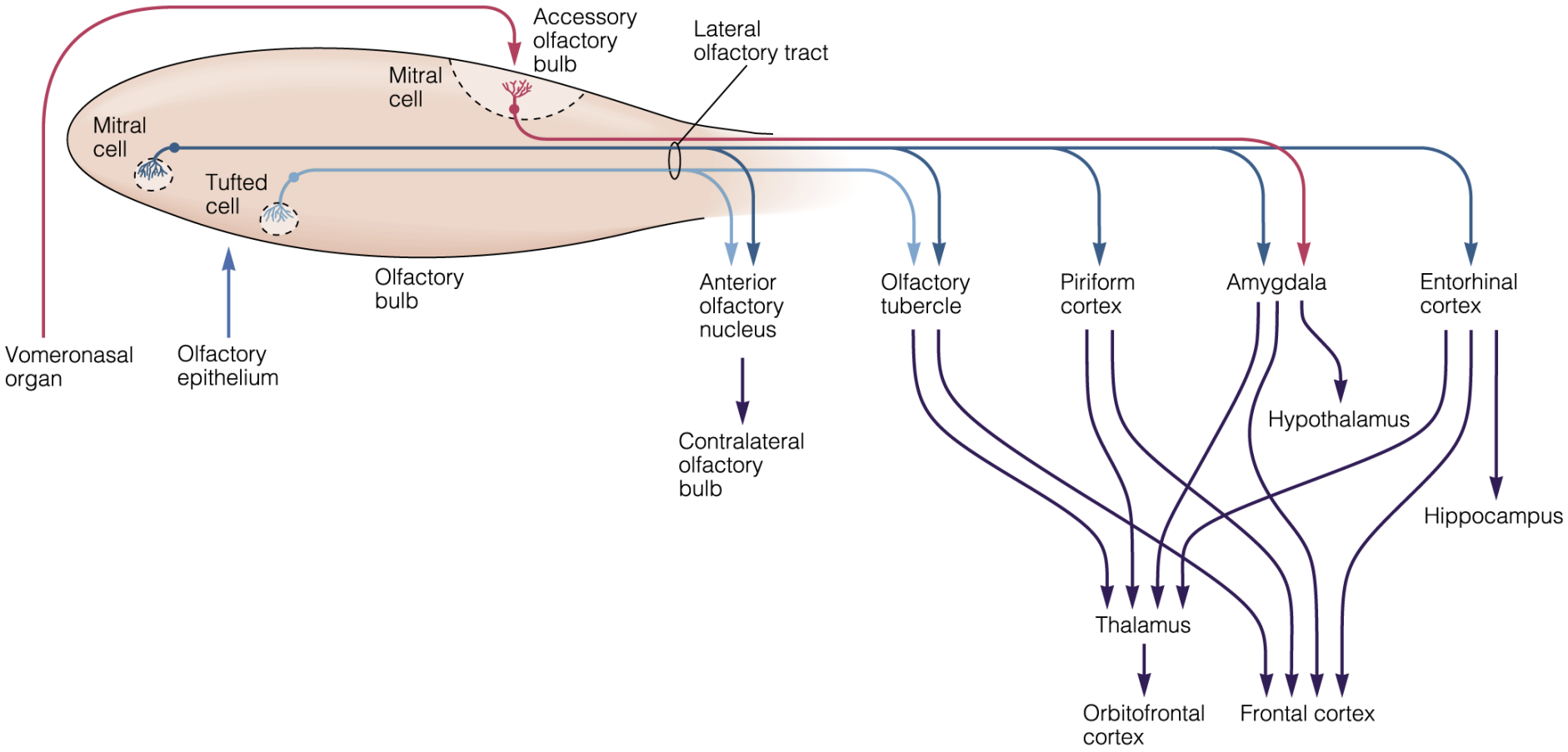
Mouse – **1035**
Rat – **1207**
Dog – **811**
Human – **387**

olfactory receptor cells in nasal cavity



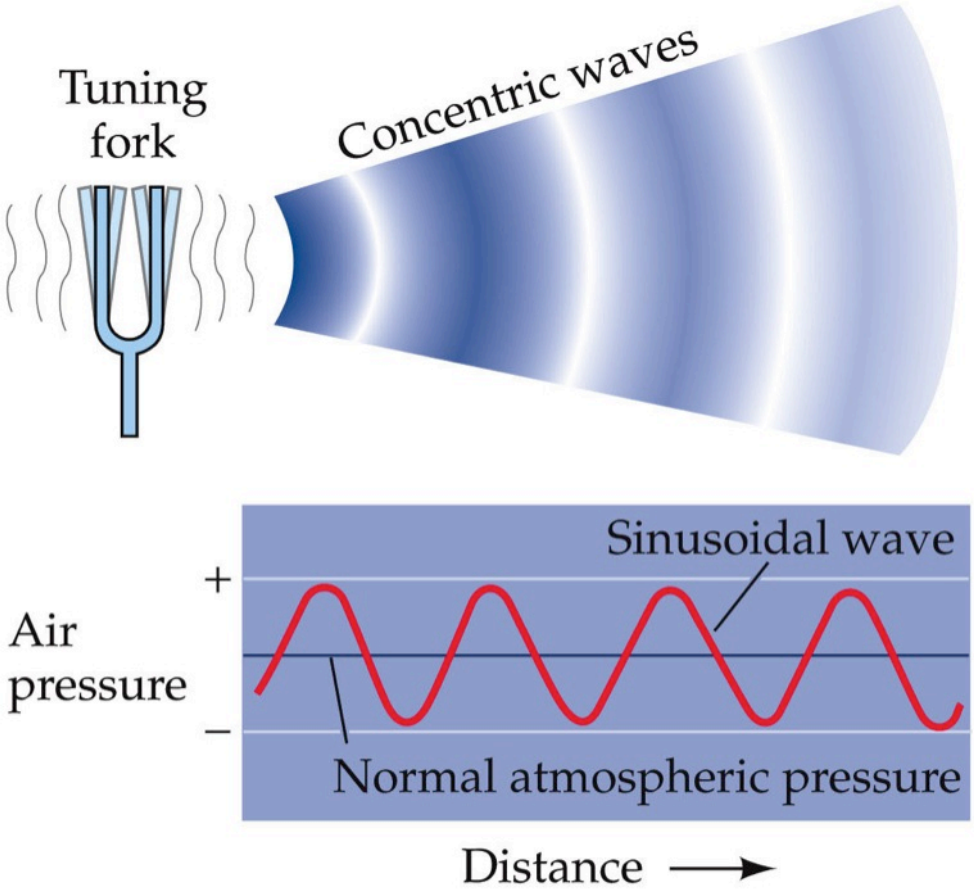

Olfactory bulb
Rat
Human

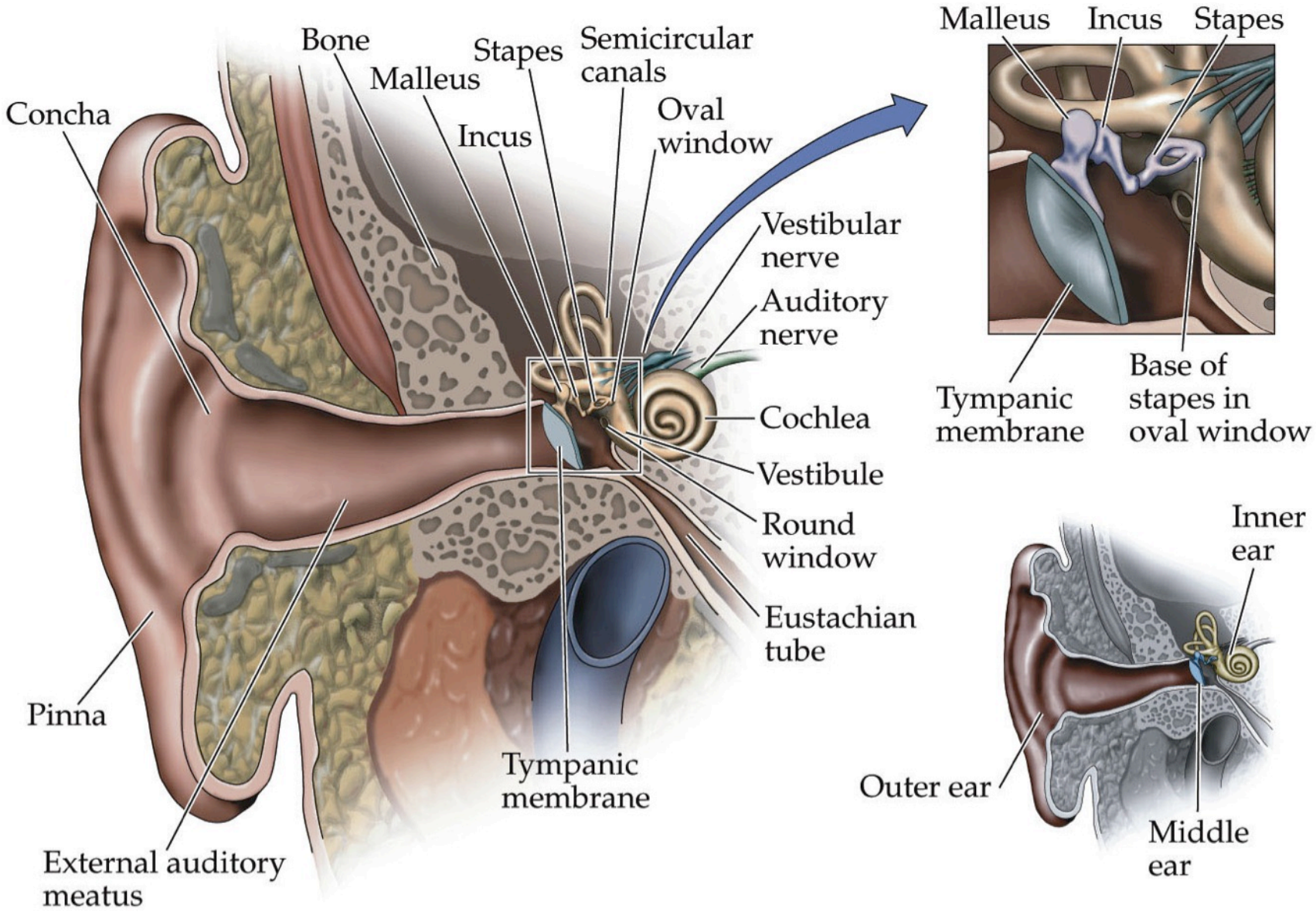
Higher Order Olfactory Processing

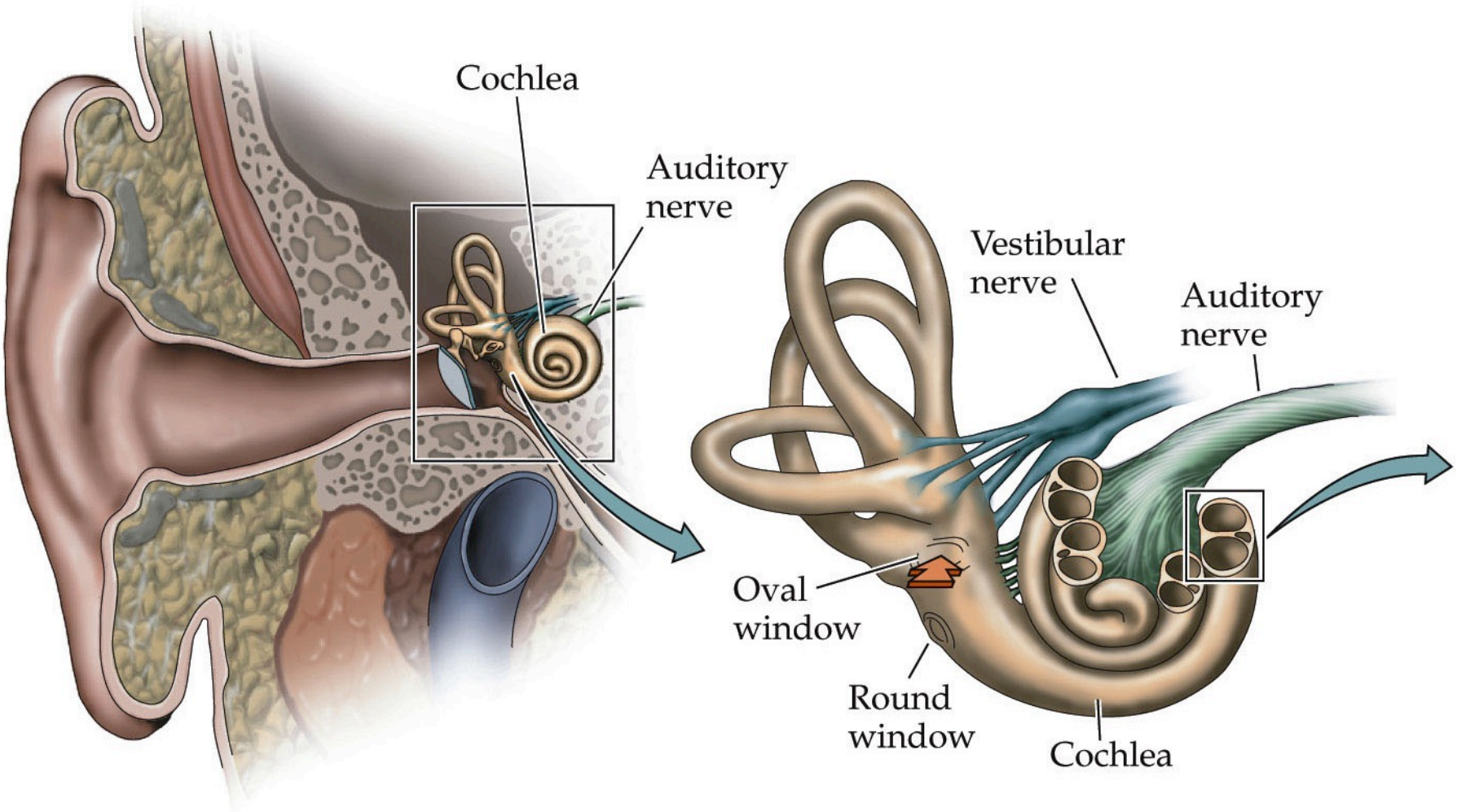


Hearing
(audition)

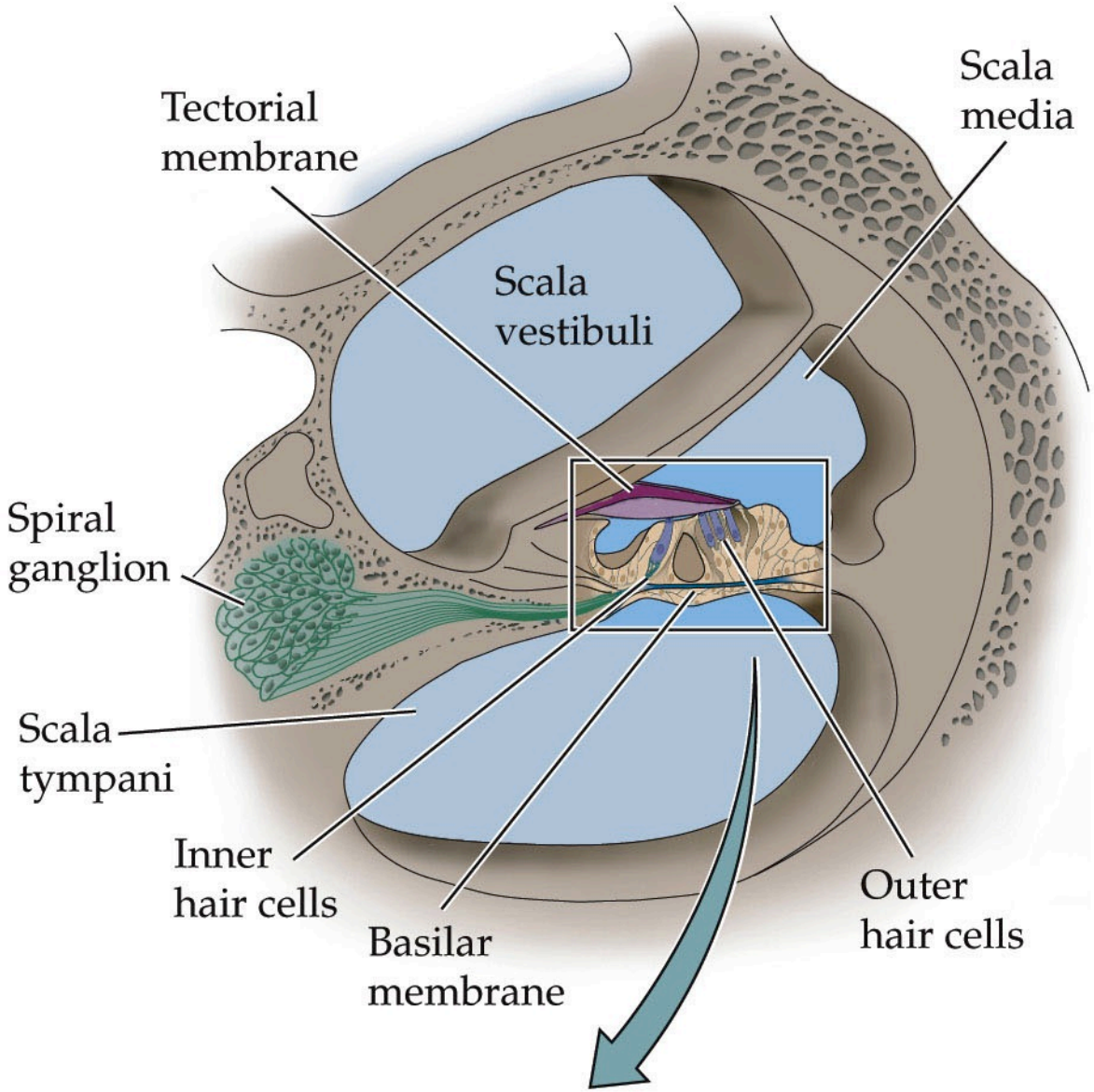
Hearing (audition)

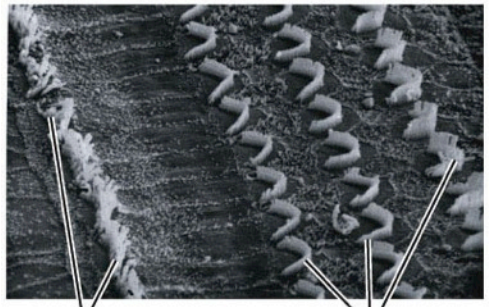



Concha
Bone
Malleus
Stapes
Incus
Semicircular canals
Oval window
Vestibular nerve
Auditory nerve
Cochlea
Vestibule
Round window
Eustachian tube
Pinna
External auditory meatus
Tympanic membrane
Malleus
Incus
Stapes
Tympanic membrane
Base of stapes in oval window
Inner ear
Outer ear
Middle ear


Cochlea
Auditory nerve
Vestibular nerve
Auditory nerve
Oval window
Round window
Cochlea

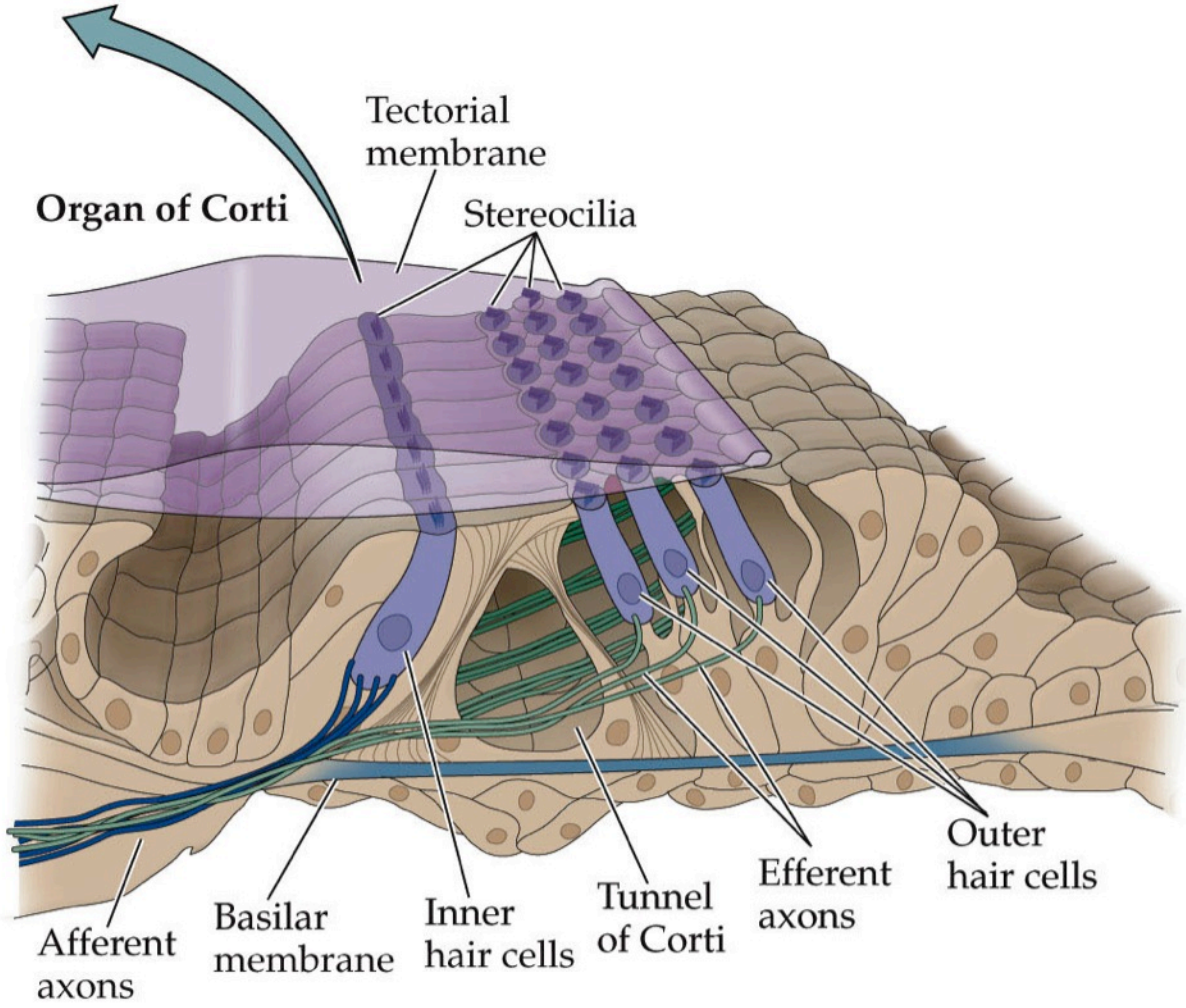
Cross section of cochlea



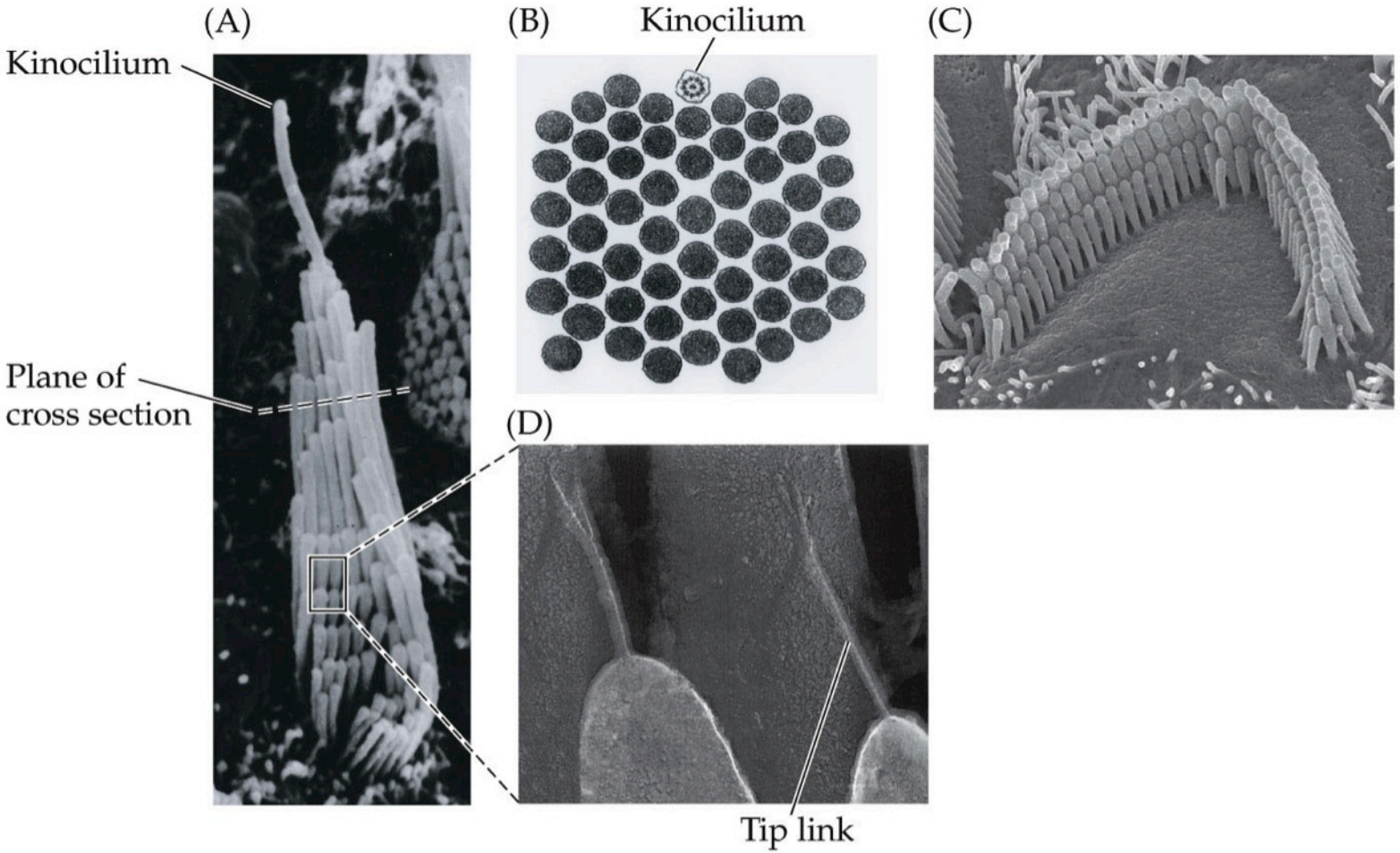


Stereocilia of inner hair cells

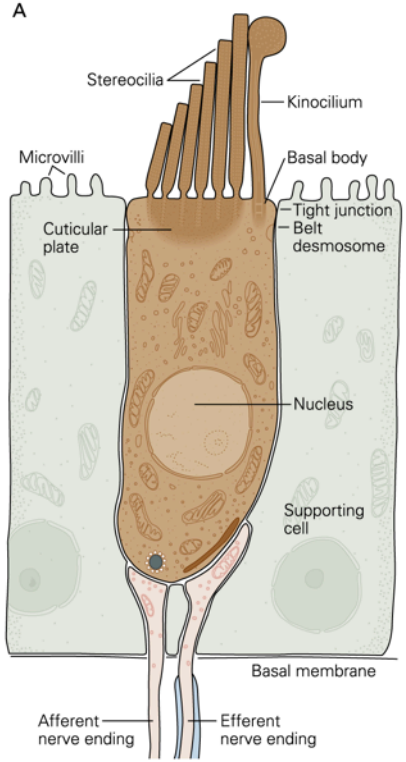
Stereocilia of outer hair cells



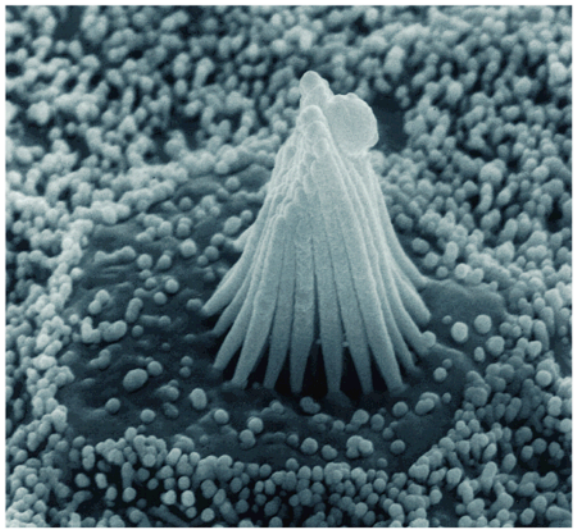
Cochlear Hair Cells



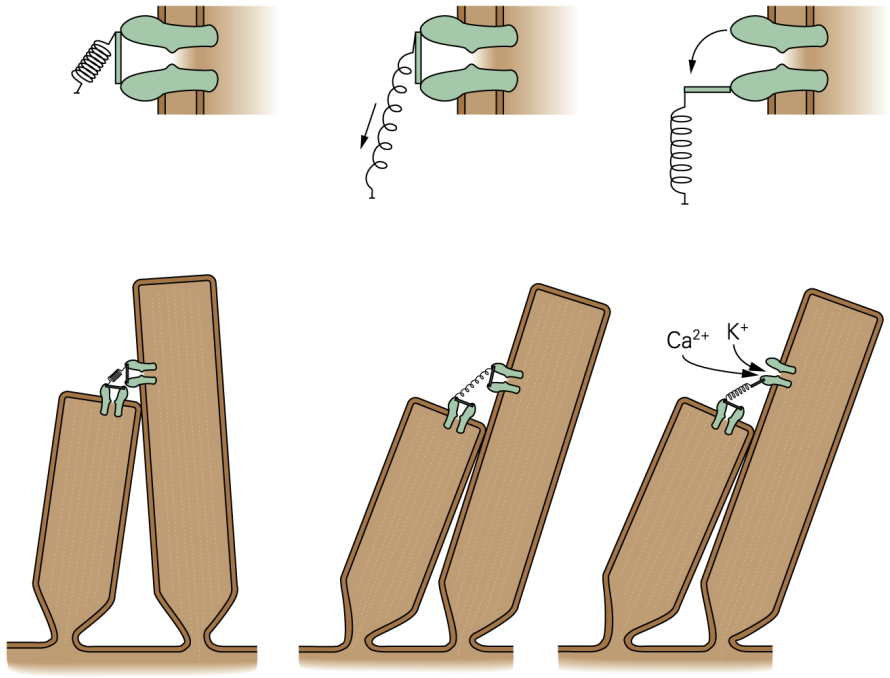
A


Stereocilia
Kinocilium
Microvilli
Basal body
Tight junction
Belt desmosome
Cuticular plate
Nucleus
Supporting cell
Basal membrane
Afferent nerve ending
Efferent nerve ending

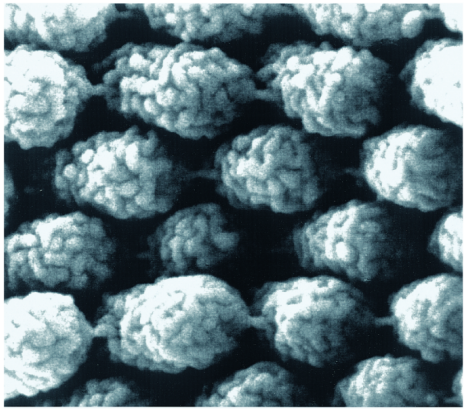
B

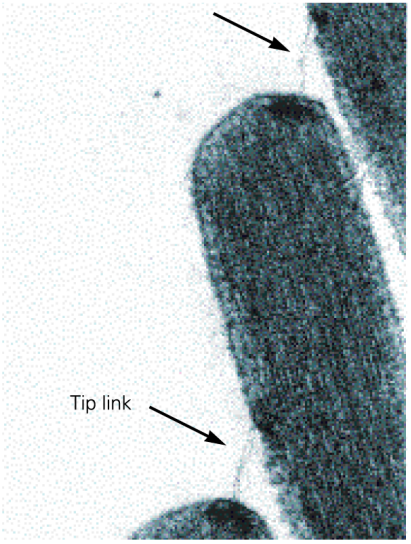


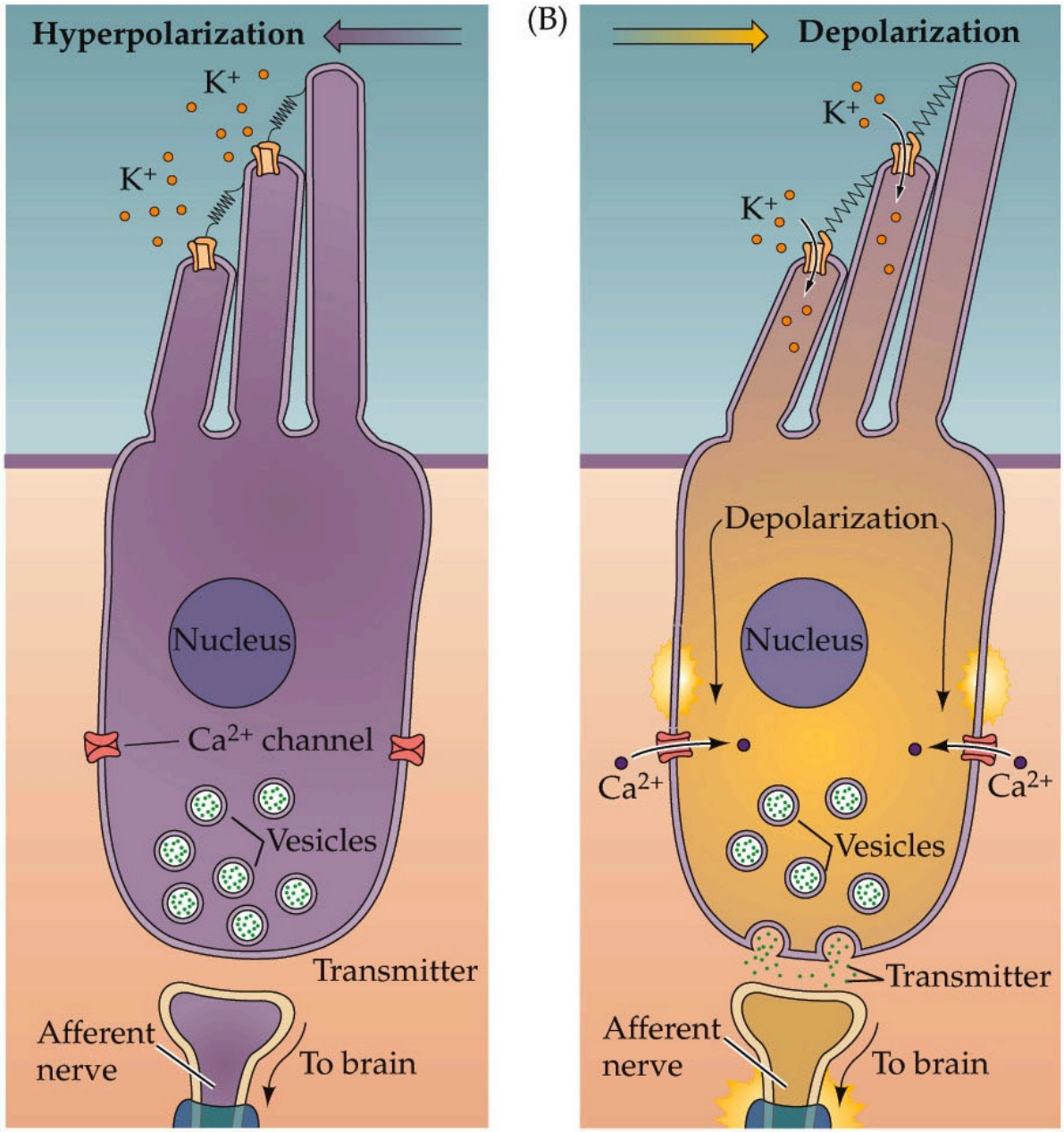
A

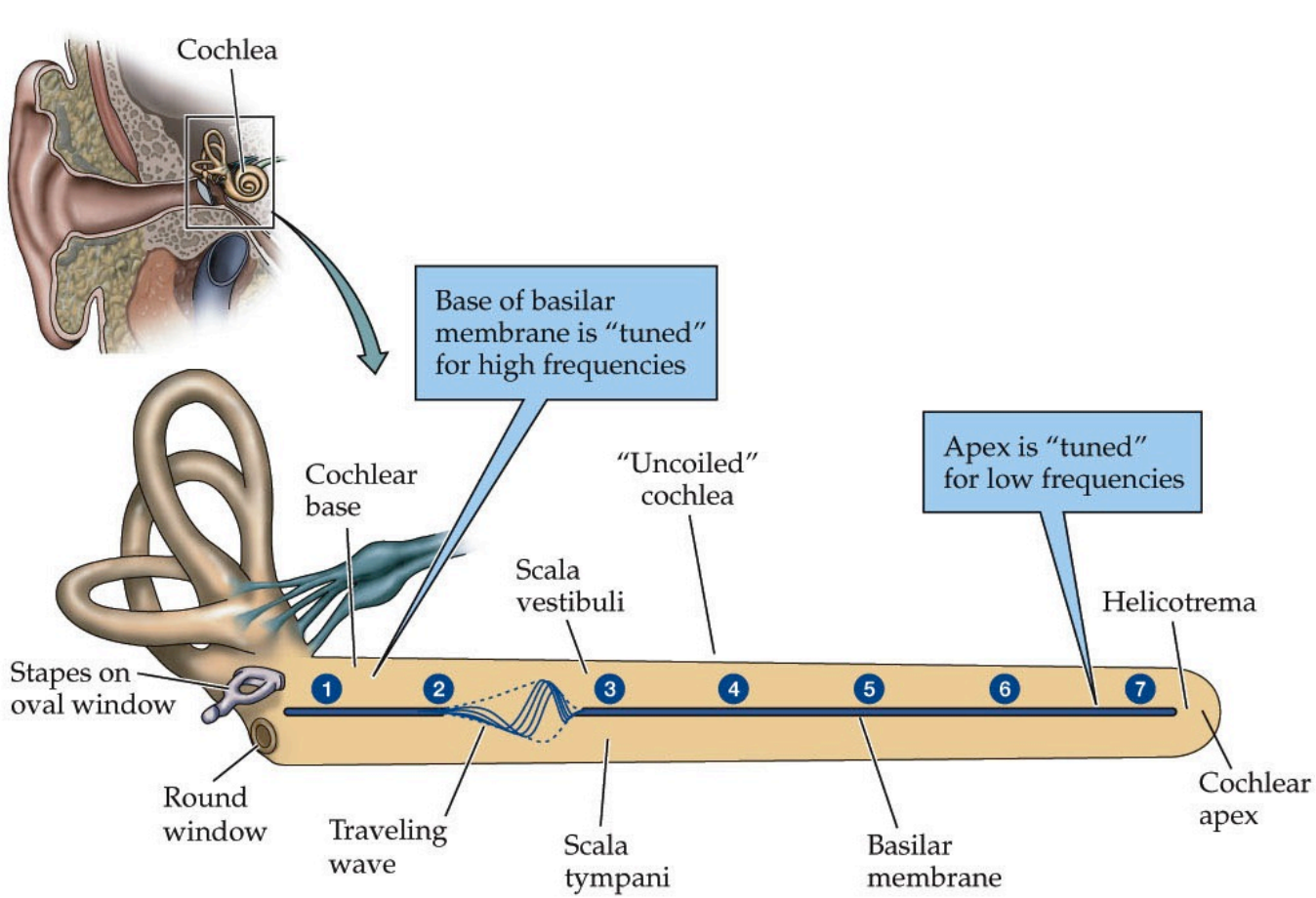

Ca^{2+}
K^{+}

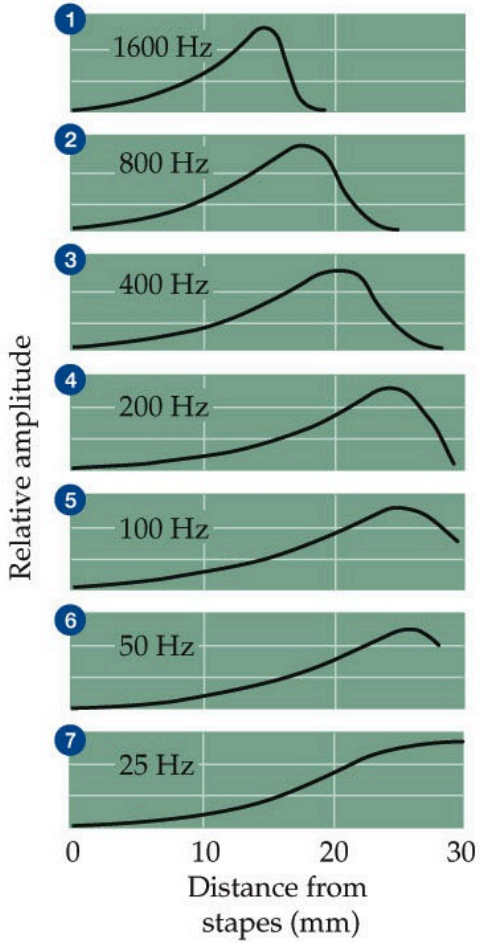
B




Tip link


Hyperpolarization
K+
K+
Nucleus
Ca2+ channel
Vesicles
Transmitter
Afferent nerve
To brain
(B)
Depolarization
K+
K+
Depolarization
Nucleus
Ca2+
Ca2+
Vesicles
Transmitter
Afferent nerve
To brain


Cochlea
Base of basilar membrane is "tuned" for high frequencies
Cochlear base
"Uncoiled" cochlea
Apex is "tuned" for low frequencies
Scala vestibuli
Helicotrema
Stapes on oval window
1
2
3
4
5
6
7
Round window
Traveling wave
Scala tympani
Basilar membrane
Cochlear apex


1
1600 Hz
2
800 Hz
3
400 Hz
4
200 Hz
5
100 Hz
6
50 Hz
7
25 Hz
Relative amplitude
0
10
20
30
Distance from stapes (mm)

Basics concepts
Part I

We can only detect what we have receptors for:

Photoreceptors: vision

Chemoreceptors: smell and taste

Mechanoreceptors: sound and touch

Thermoreceptors: heat

Basics concepts
Part II

Receptive cells

1. Are highly selective to a particular kind of stimulus- eyes are good at seeing, not so great at hearing

2. Have a receptive field- ear hair cells respond to only a particular range of frequencies

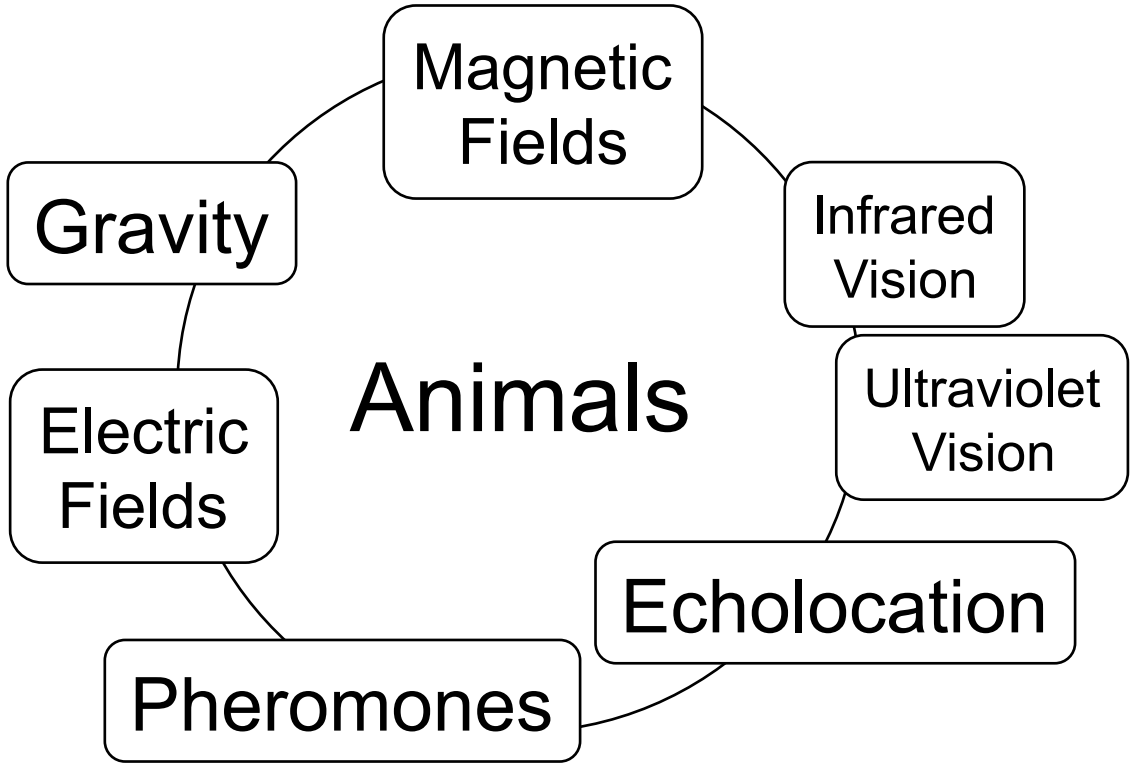
Basics of perception
Part III

Amplification and Transduction

1. Receptor cells can detect very weak signals and amplify them- for example, a photoreceptive cell can detect a single photon of light.

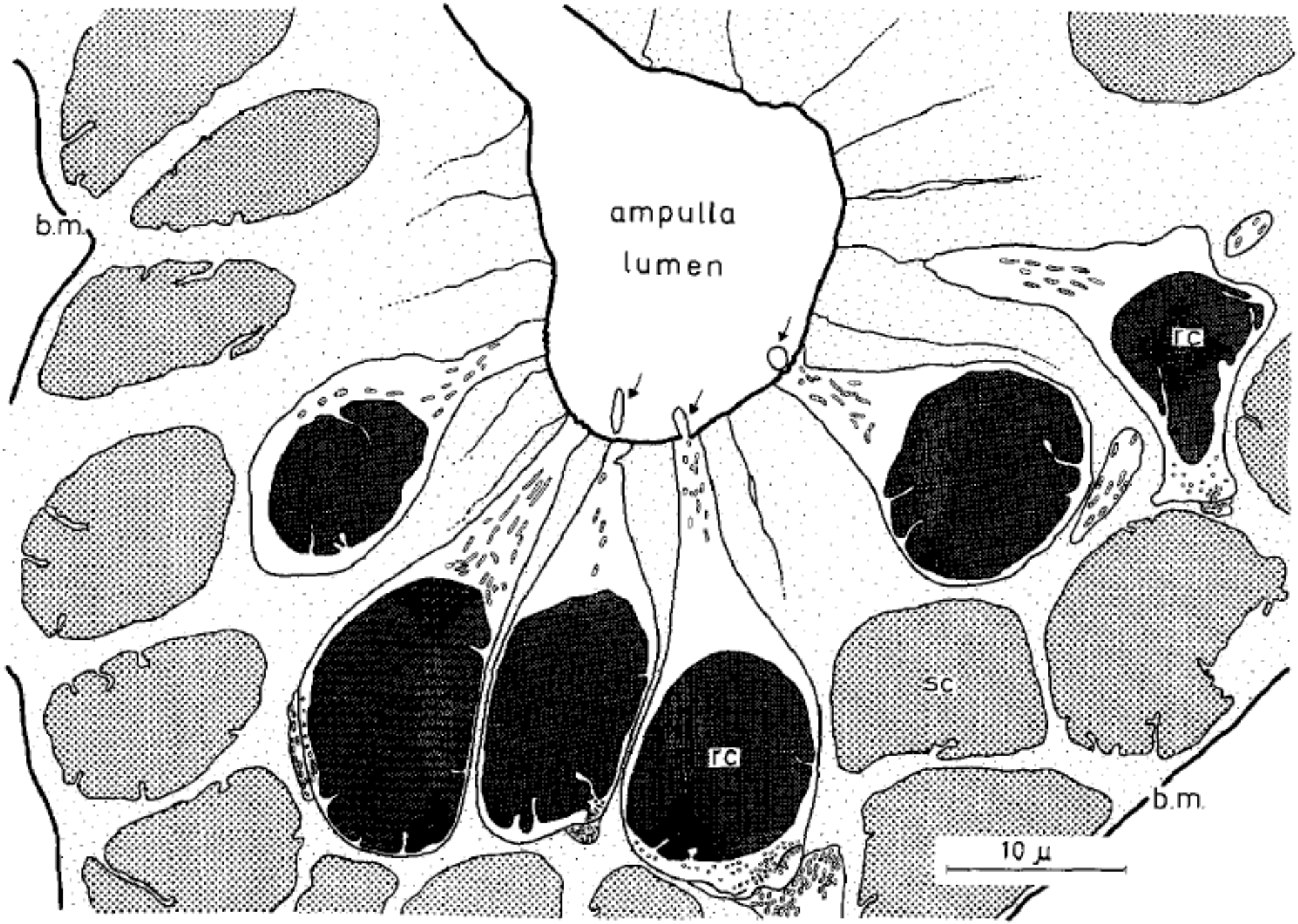
2. Once a receptor cell is activated the signal is *transduced*: the environmental signal (the stimulus) is converted into a cellular response- usually the firing of a neuron

Special animal senses



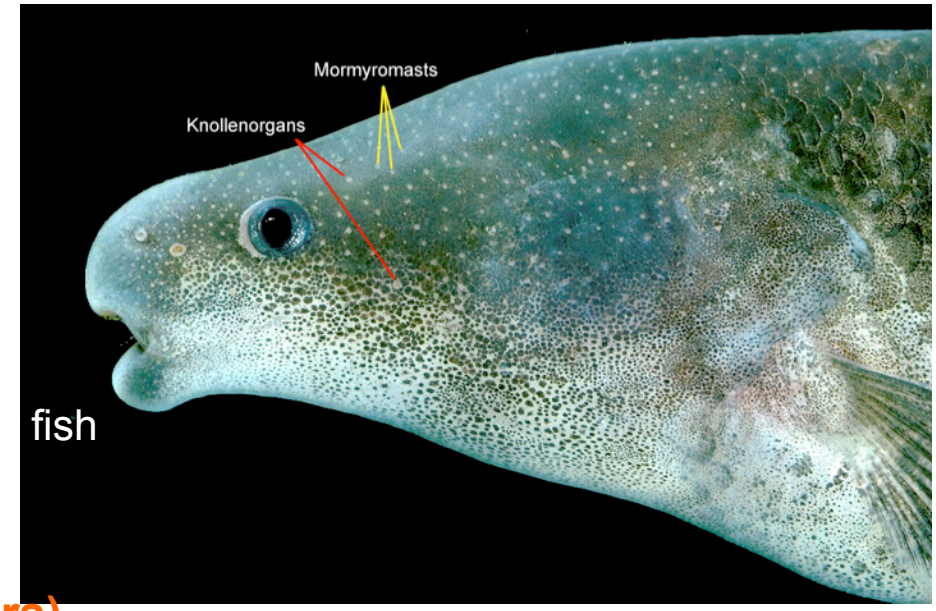
Electroreception

ampullae of Lorenzini



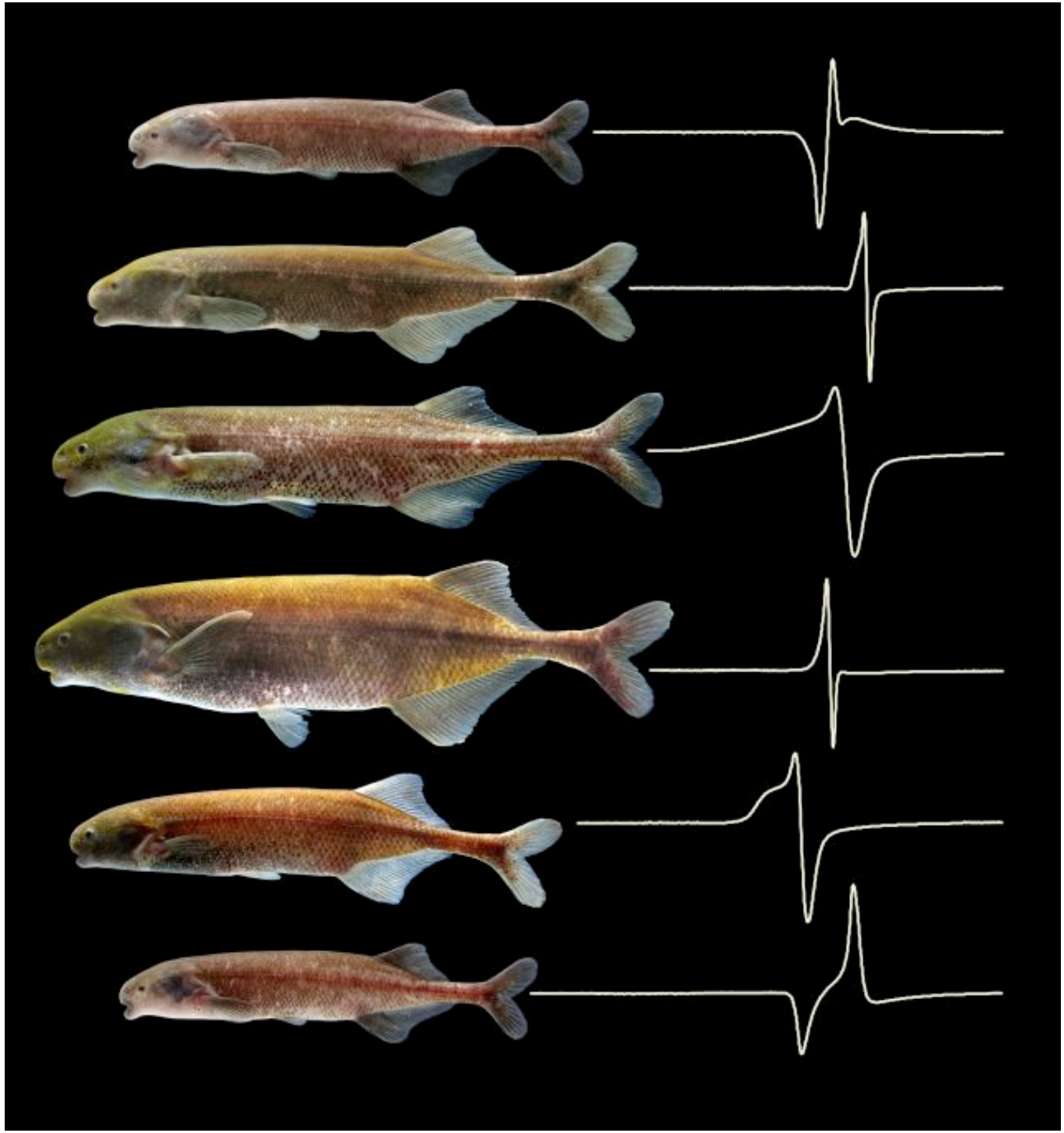
Roth and Tscharntke, 1976

ampullary electroreceptors



mormyromasts (tuberous electroreceptors)

knollenorgans



Supersenses

bats

Journal club

The Cells and Logic for Mammalian Sour Taste detection

Angela L. Huang, Xiaoke Chen, Mark A. Hoon[2], Jayaram Chandrashekar, Wei Guo, Dimitri Tränkner, Nicholas J. P. Ryba[2], and Charles S. Zuker[*]

Figure 1

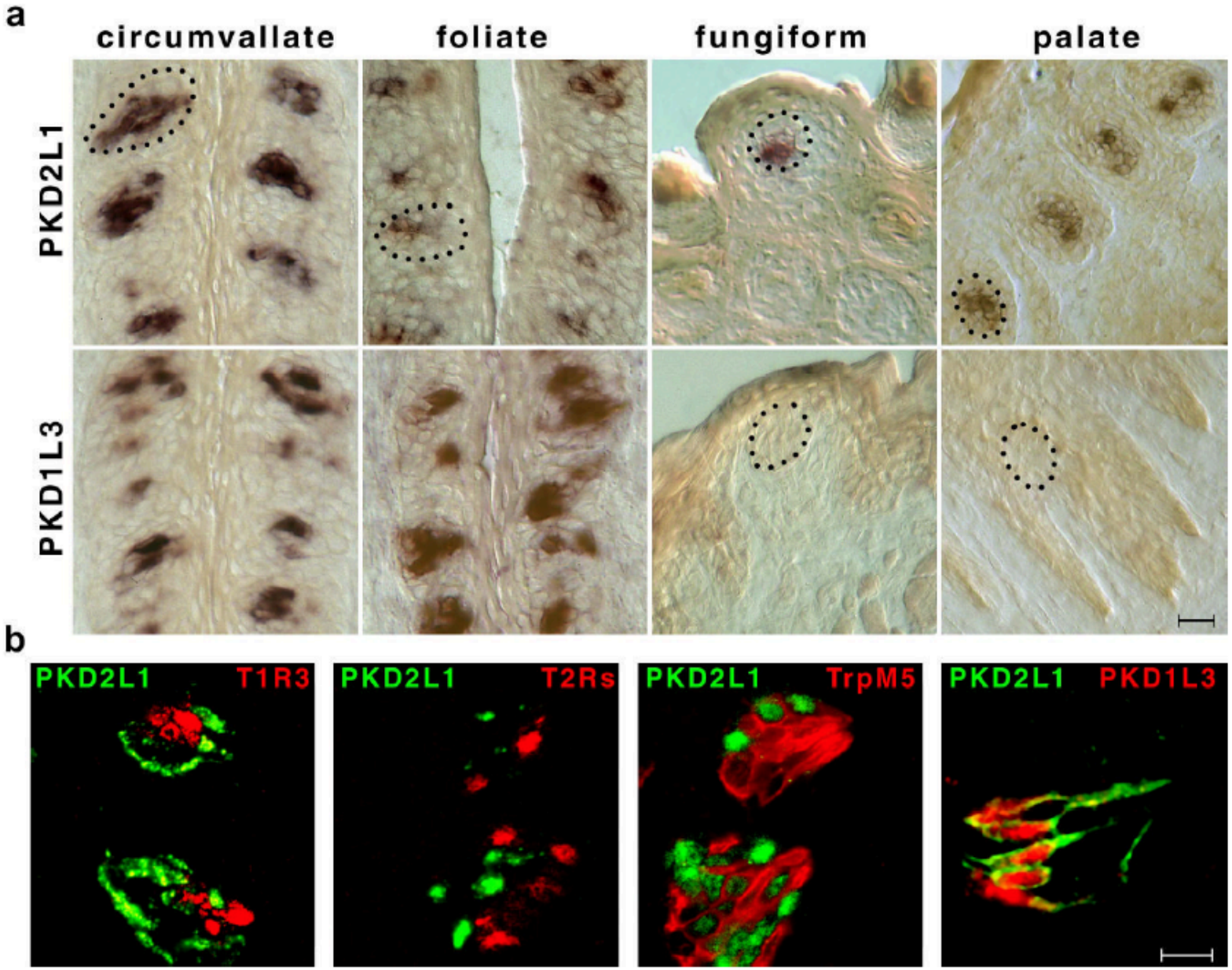

a
circumvallate
foliate
fungiform
palate
PKD2L1
PKD1L3
b
PKD2L1 T1R3
PKD2L1 T2Rs
PKD2L1 TrpM5
PKD2L1 PKD1L3

Figure 2a

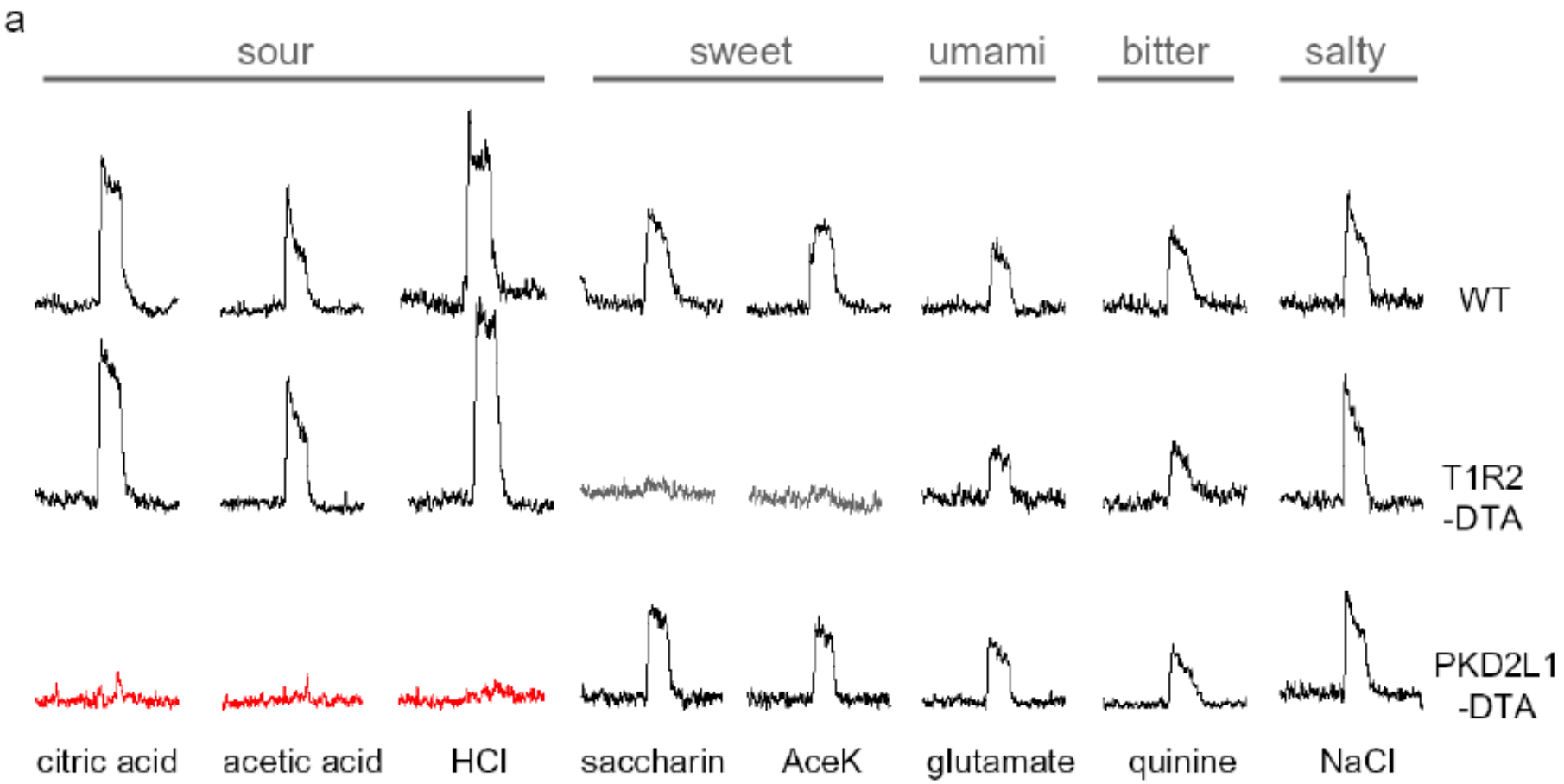

a
sour
sweet
umami
bitter
salty
WT
T1R2
-DTA
PKD2L1
-DTA
citric acid
acetic acid
HCl
saccharin
AceK
glutamate
quinine
NaCl

Figure 2b and c

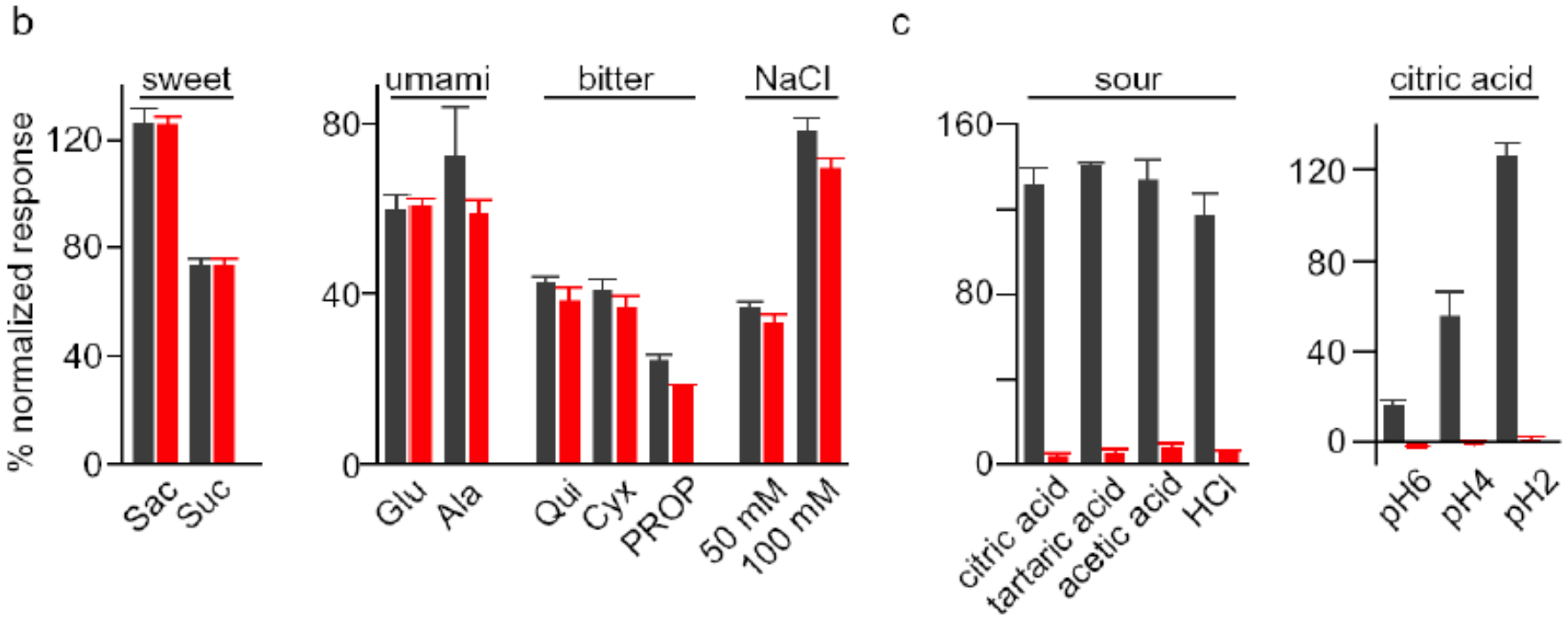


Figure 3

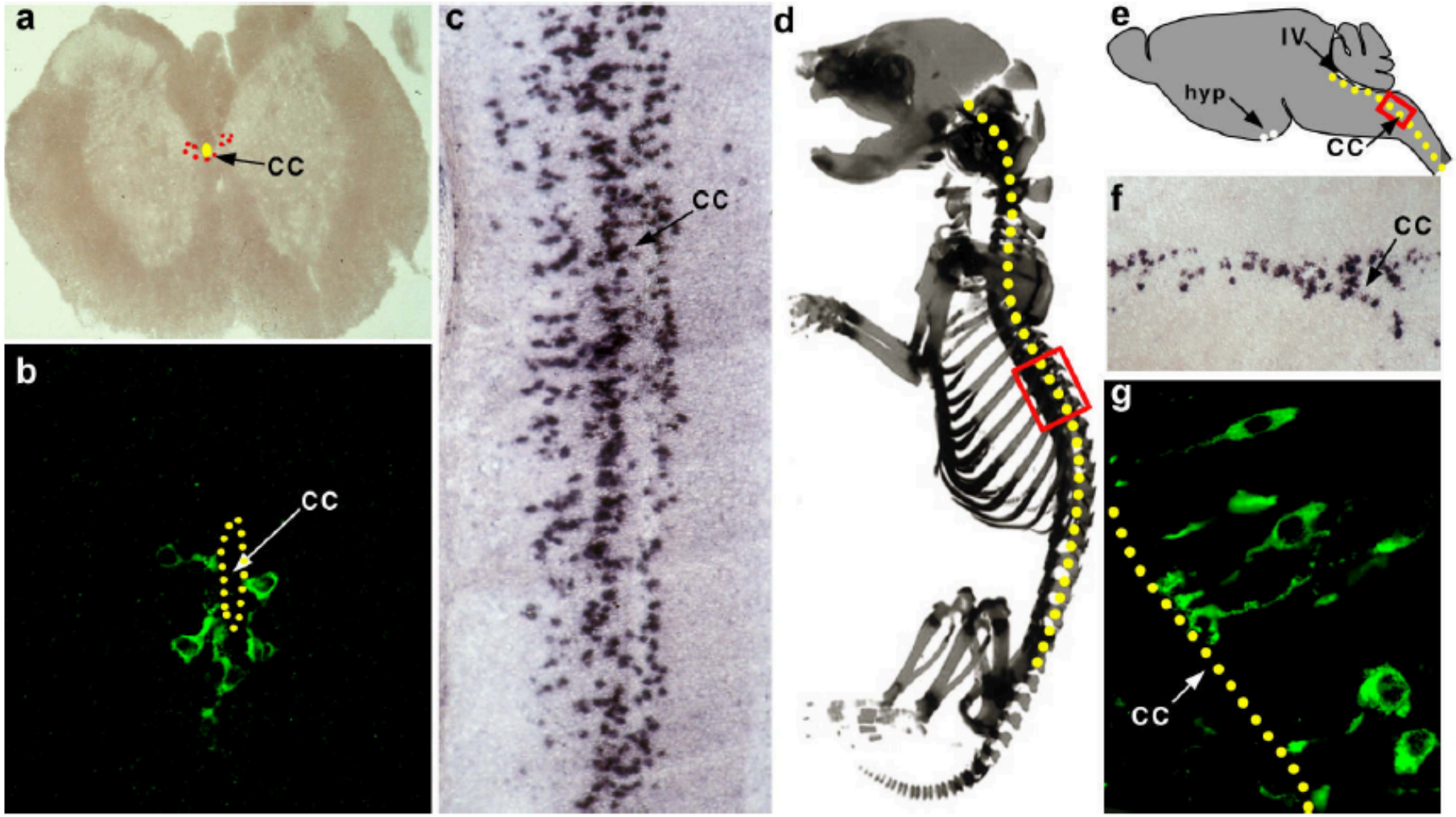
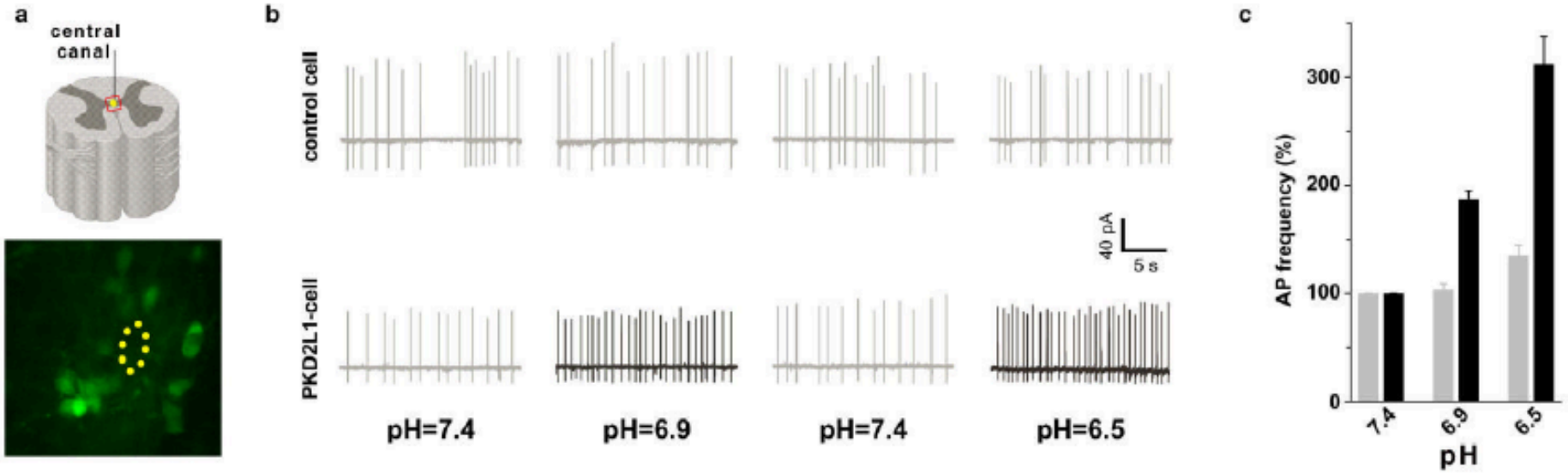
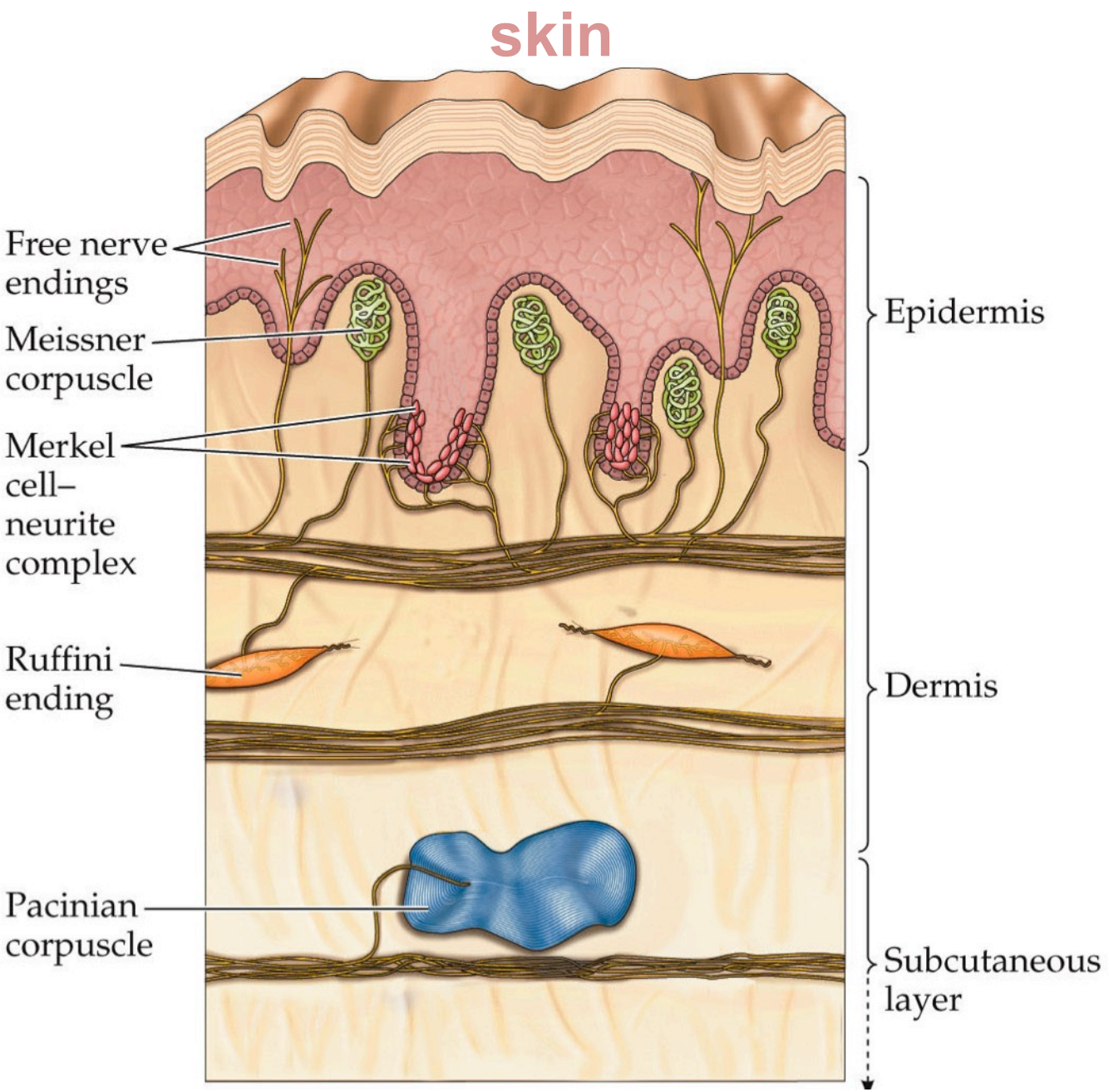


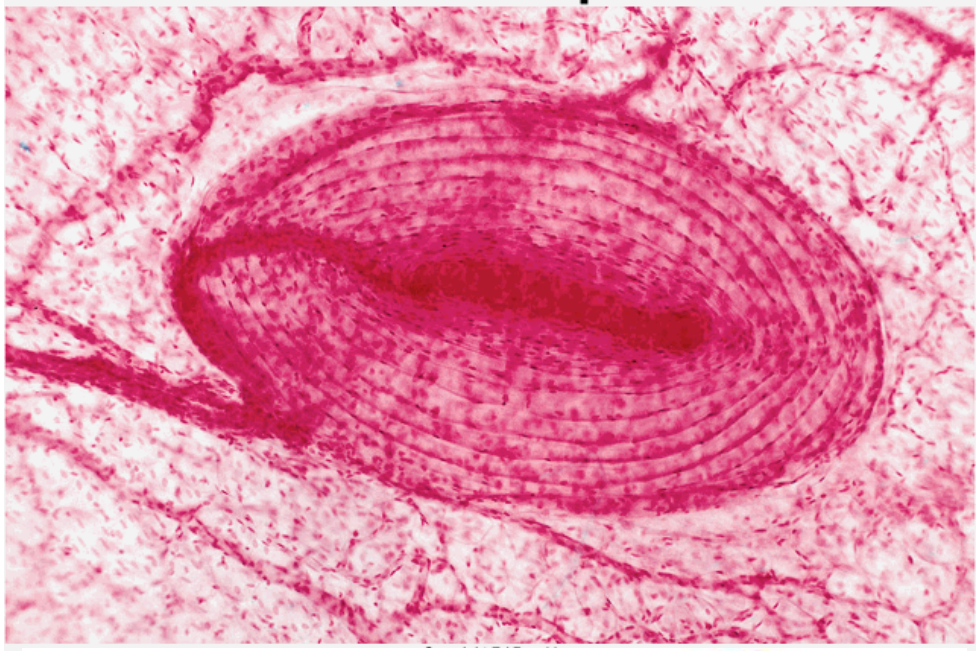
Figure 4

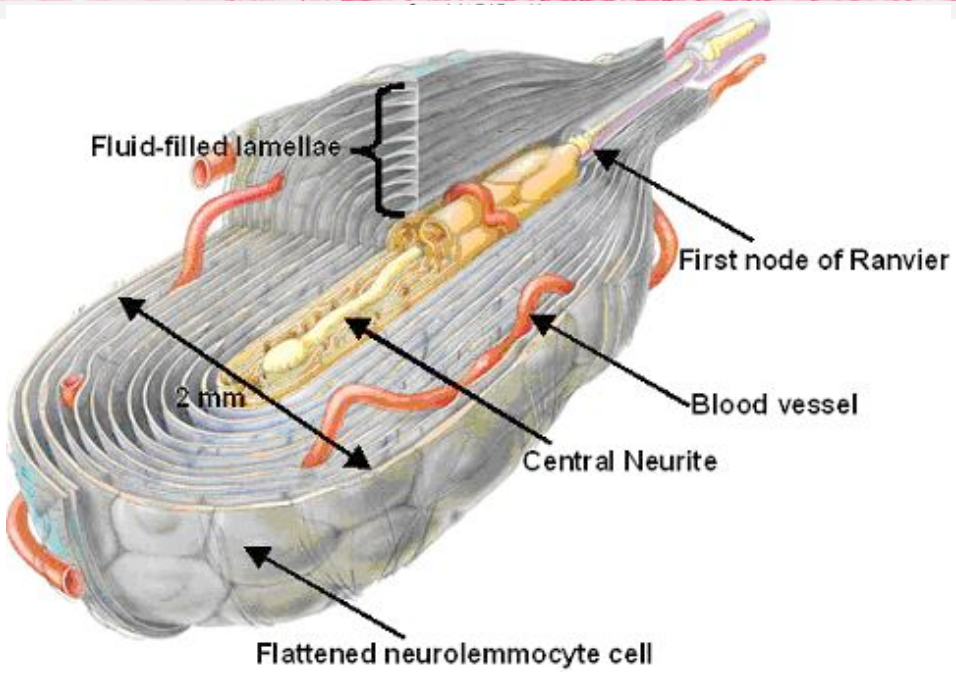

a
central canal
b
control cell
PKD2L1-cell
40 pA
5 s
pH=7.4
pH=6.9
pH=7.4
pH=6.5
c
AP frequency (%)
300
200
100
0
7.4
6.9
6.5
pH

Touch

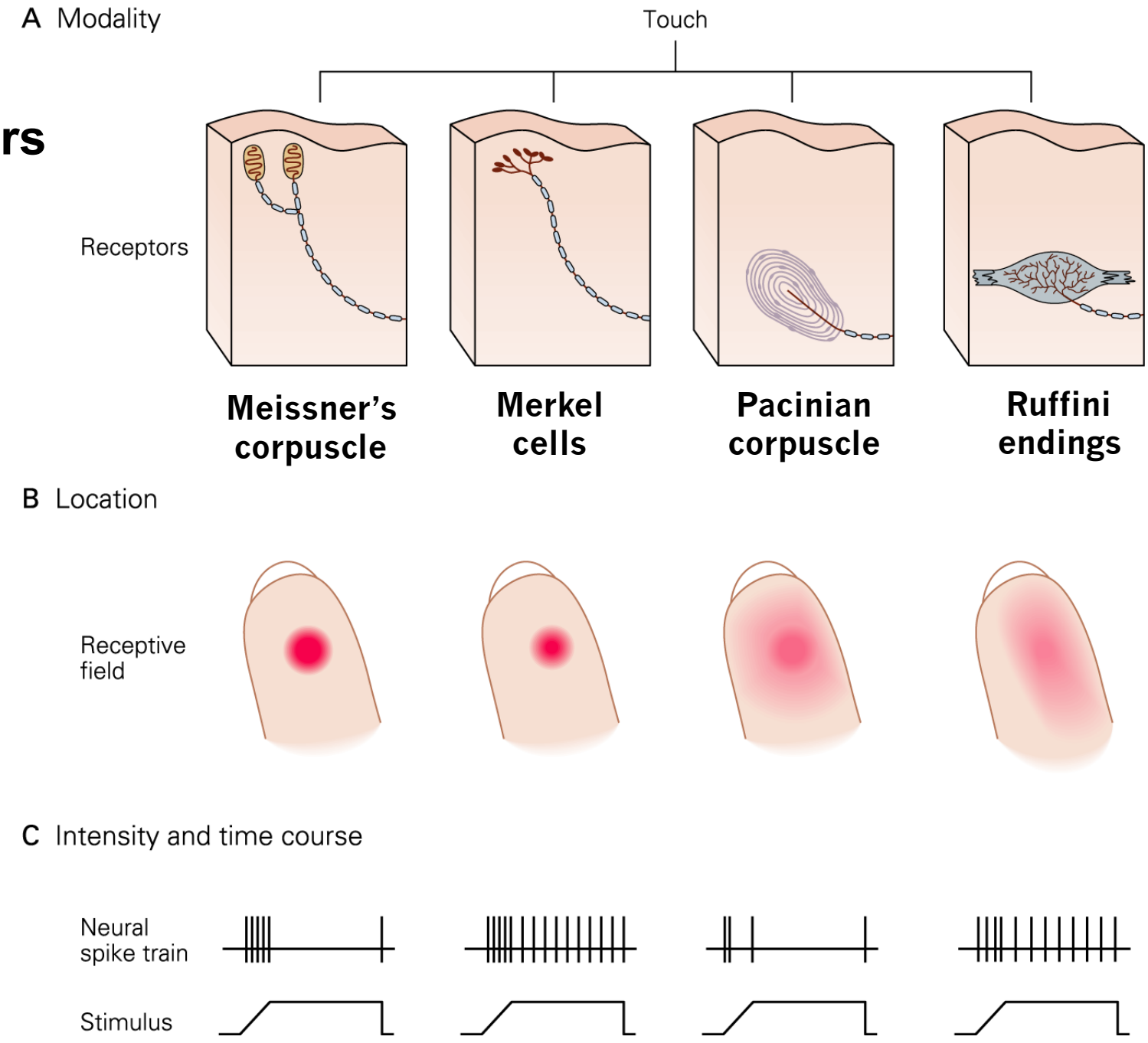

skin
Free nerve endings
Meissner corpuscle
Merkel cell–neurite complex
Ruffini ending
Pacinian corpuscle
Epidermis
Dermis
Subcutaneous layer

Pacinian Corpuscle

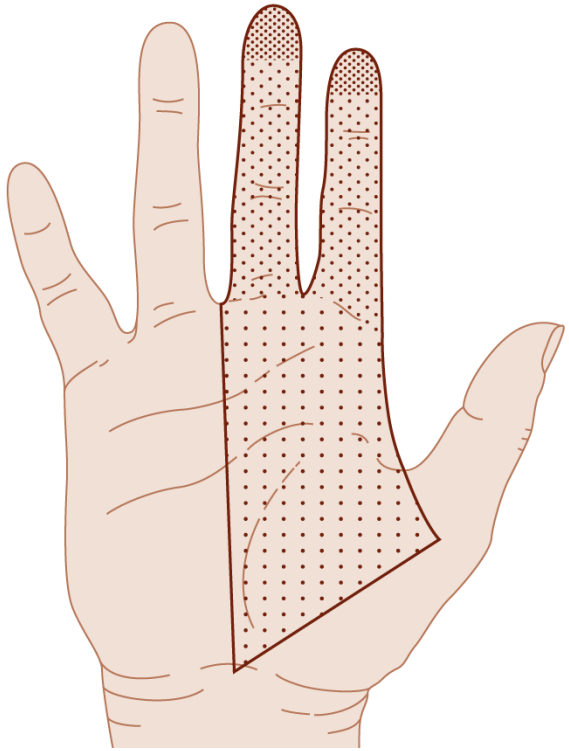




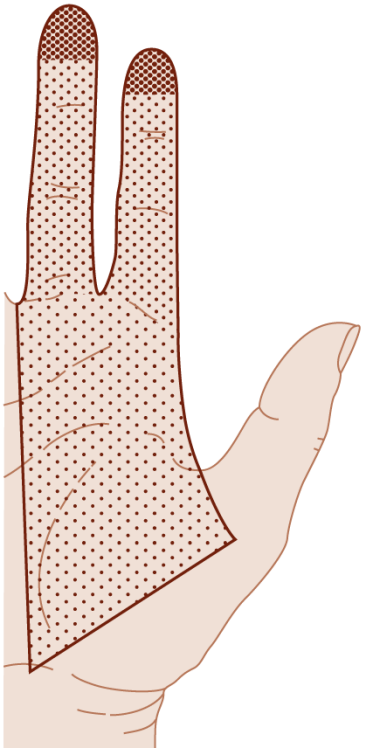
Touch Receptors



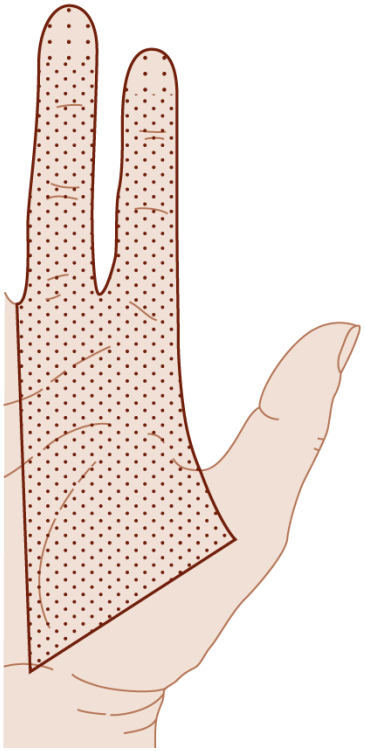
Meissner's corpuscle



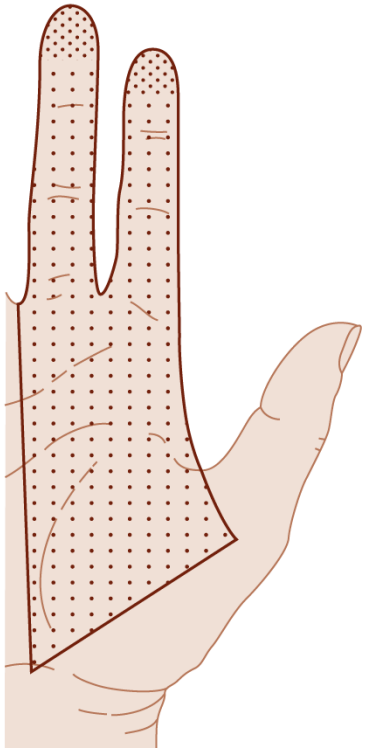
Merkel cells

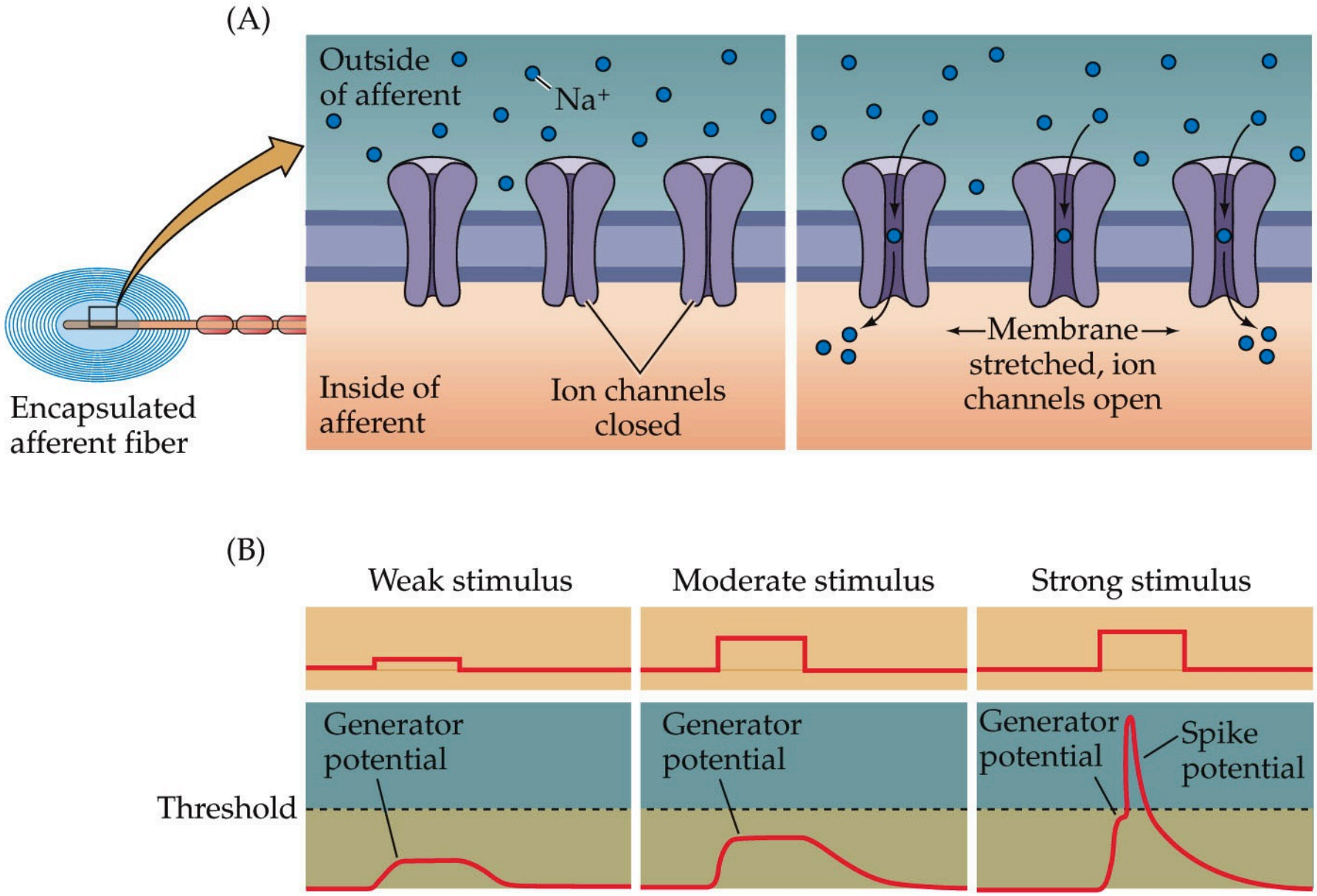


Pacinian corpuscle

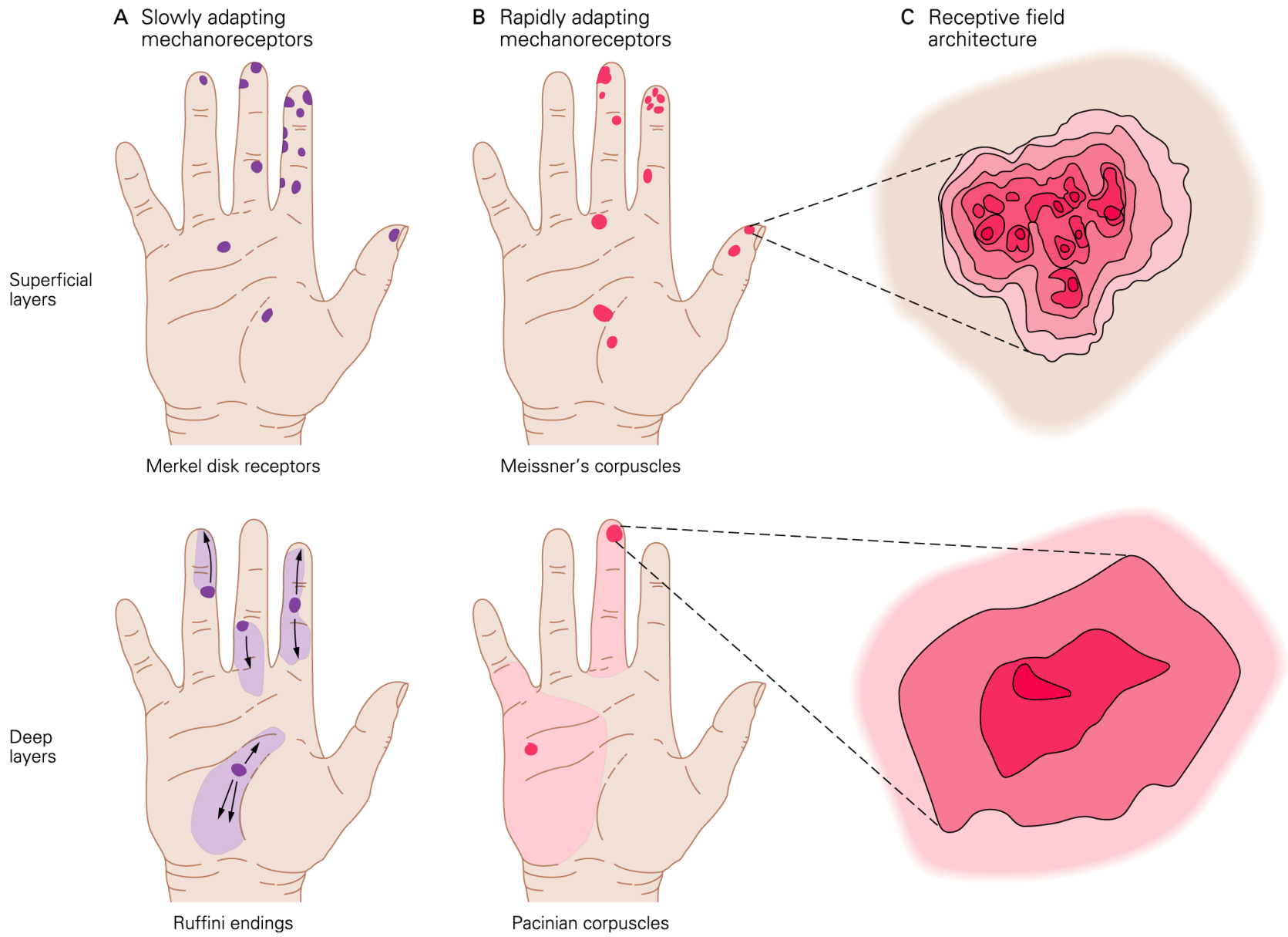


Ruffini endings

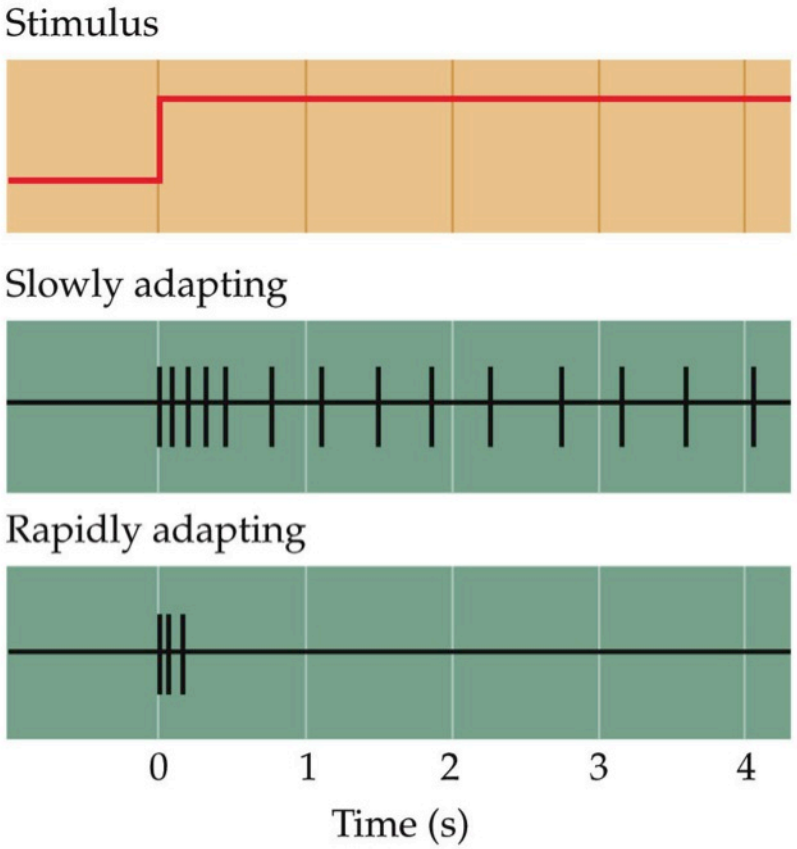


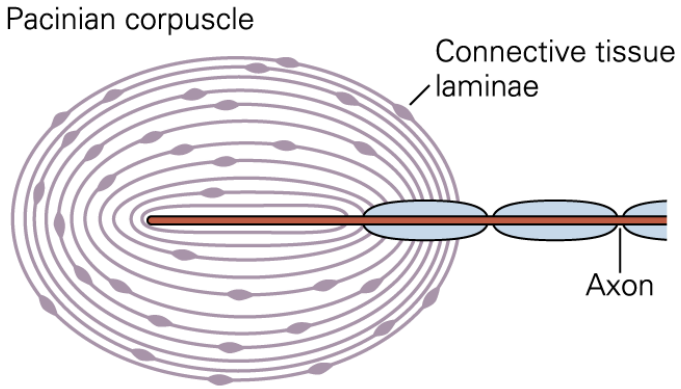

(A)
Outside of afferent
Na^+
Inside of afferent
Ion channels closed
Membrane stretched, ion channels open
Encapsulated afferent fiber
(B)
Weak stimulus
Moderate stimulus
Strong stimulus
Generator potential
Generator potential
Generator potential
Spike potential
Threshold

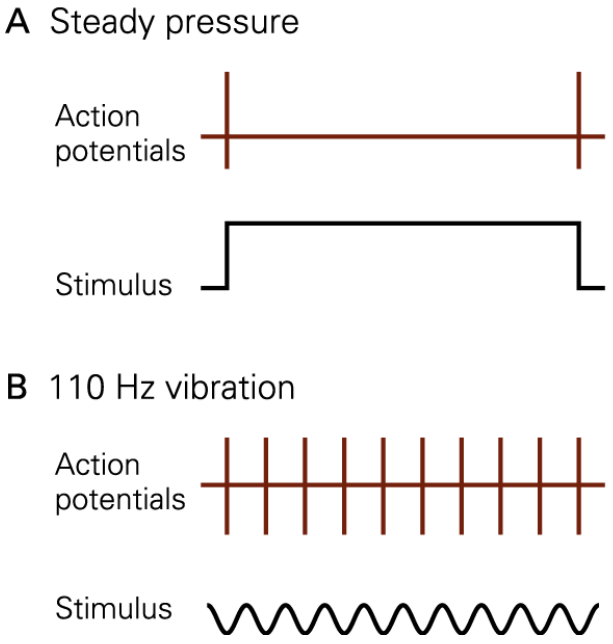
Receptive Fields



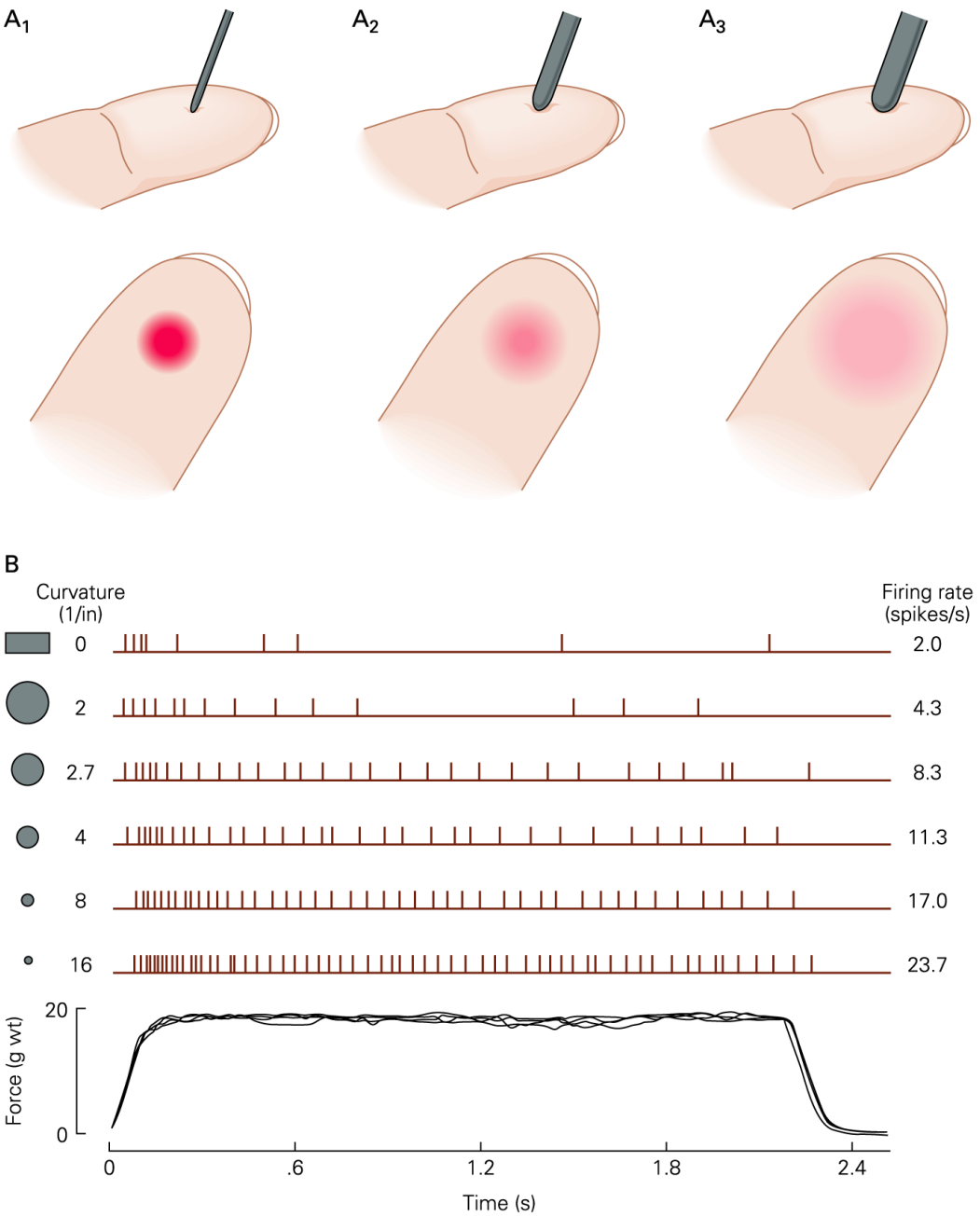
Adaptation

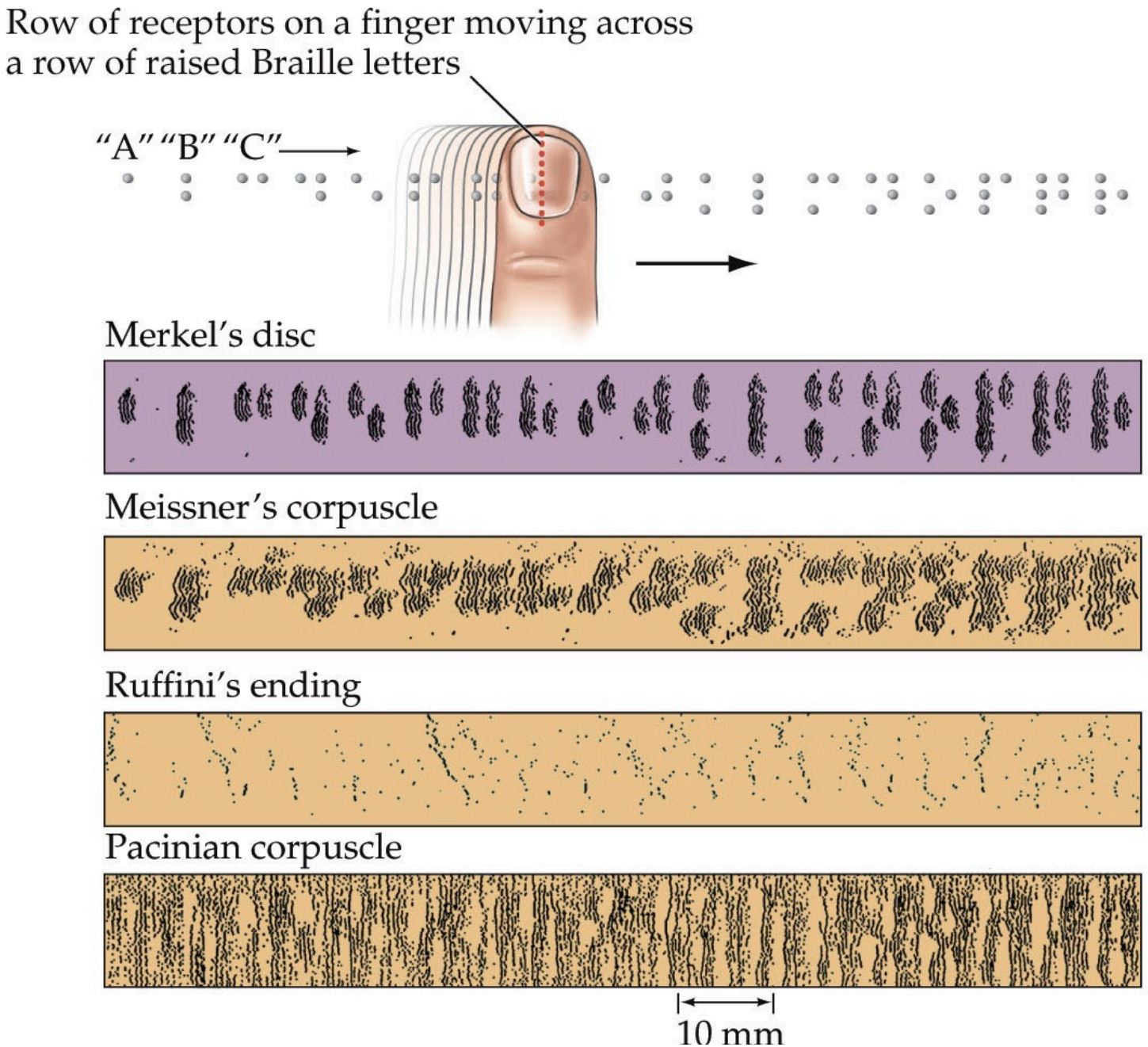

Stimulus
Slowly adapting
Rapidly adapting
0
1
2
3
4
Time (s)


Pacinian corpuscle
Connective tissue
laminae
Axon

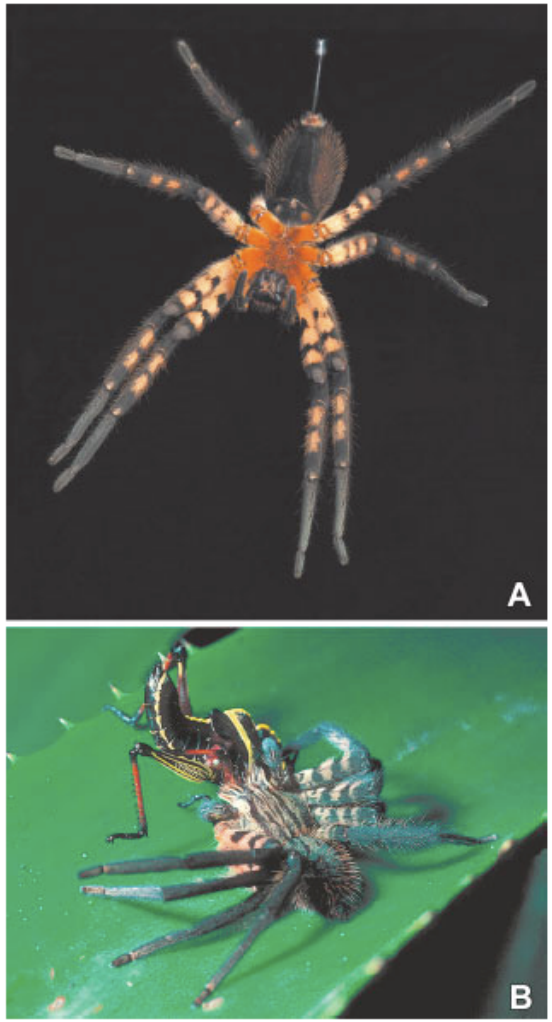

A Steady pressure
Action
potentials
Stimulus
B 110 Hz vibration
Action
potentials
Stimulus

Stimulus Tuning

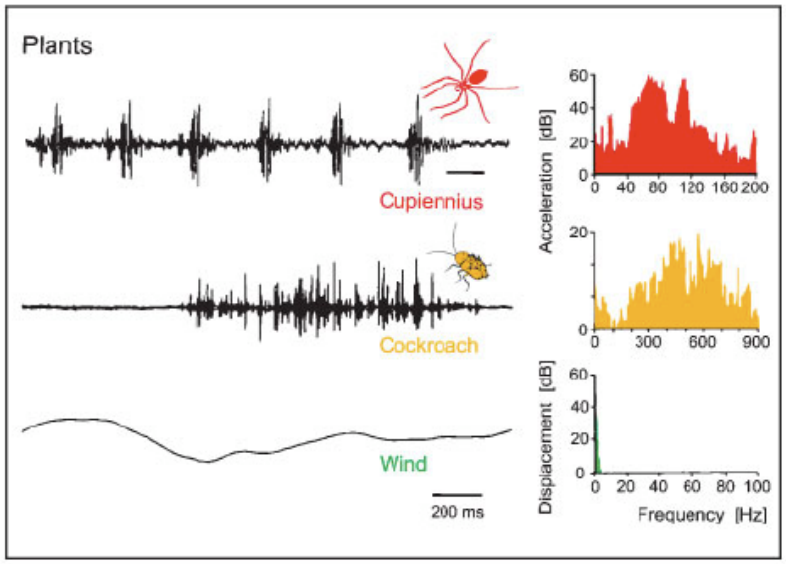


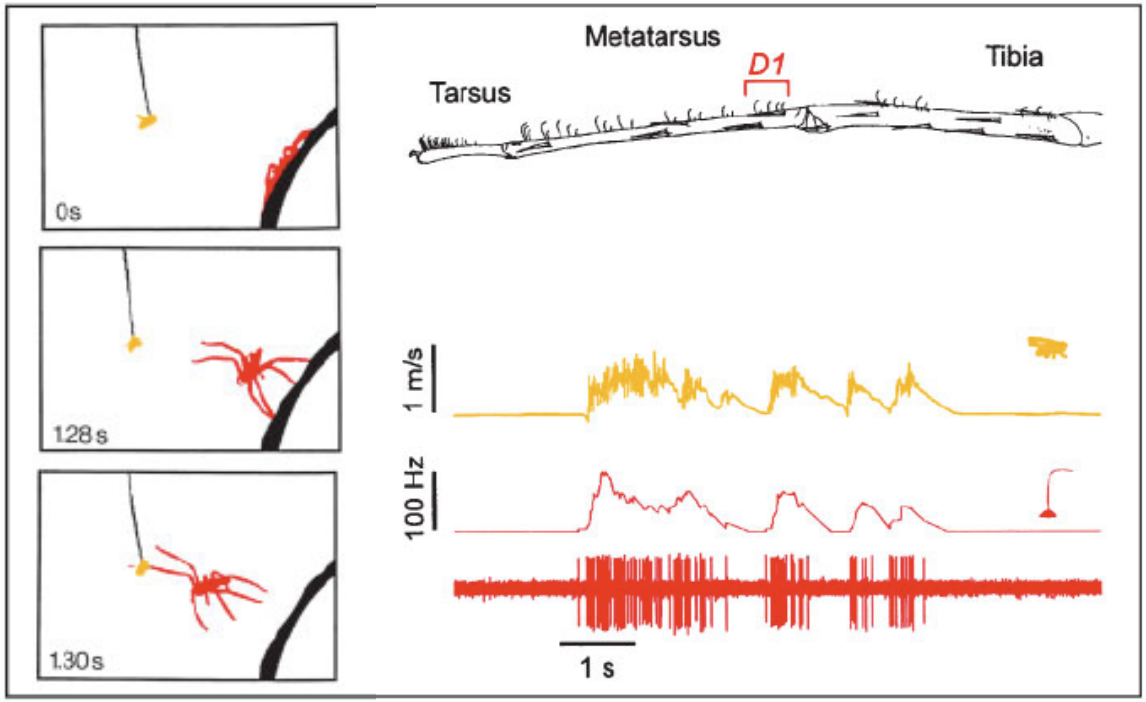

Row of receptors on a finger moving across a row of raised Braille letters
"A" "B" "C"
Merkel's disc
Meissner's corpuscle
Ruffini's ending
Pacinian corpuscle
10 mm

The Spider's Perceptual World is Vibrational

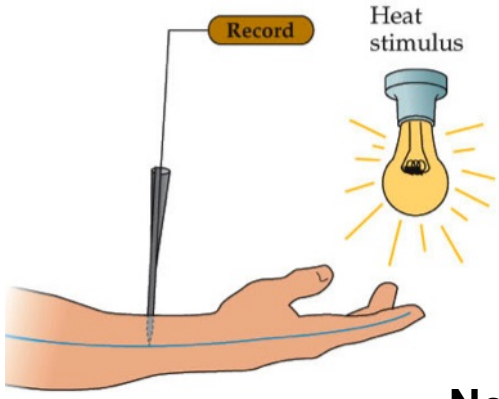


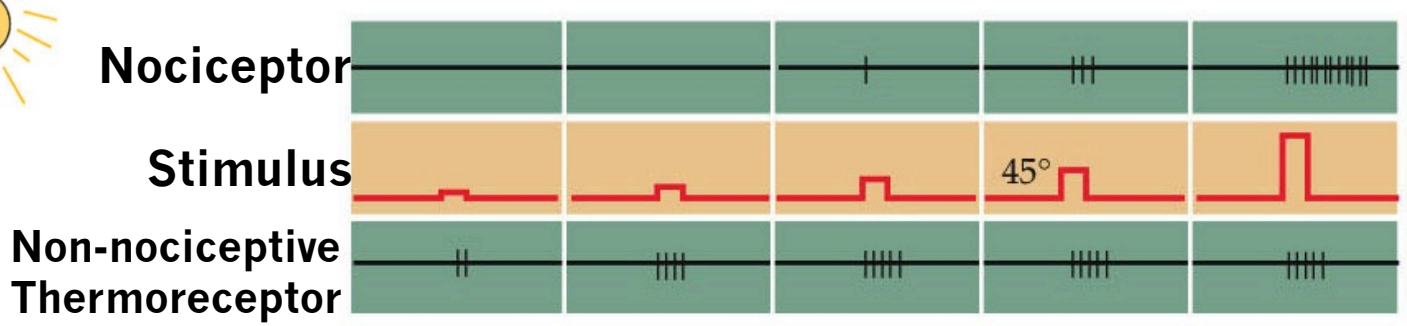
Cupiennius salei

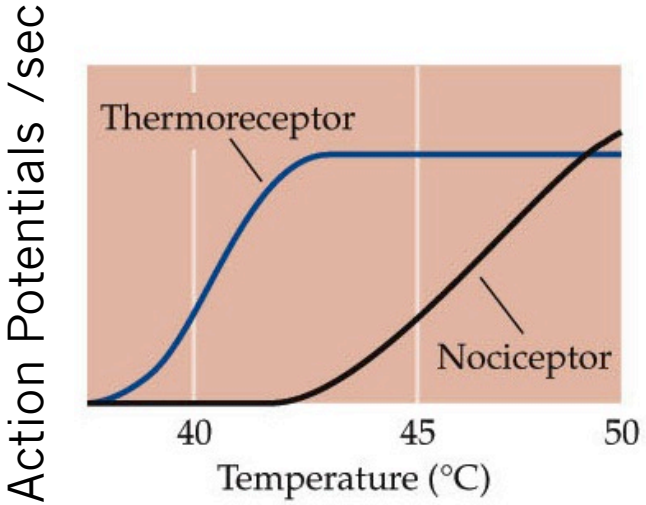




Pain 1) Response of normal receptors to extreme stimuli

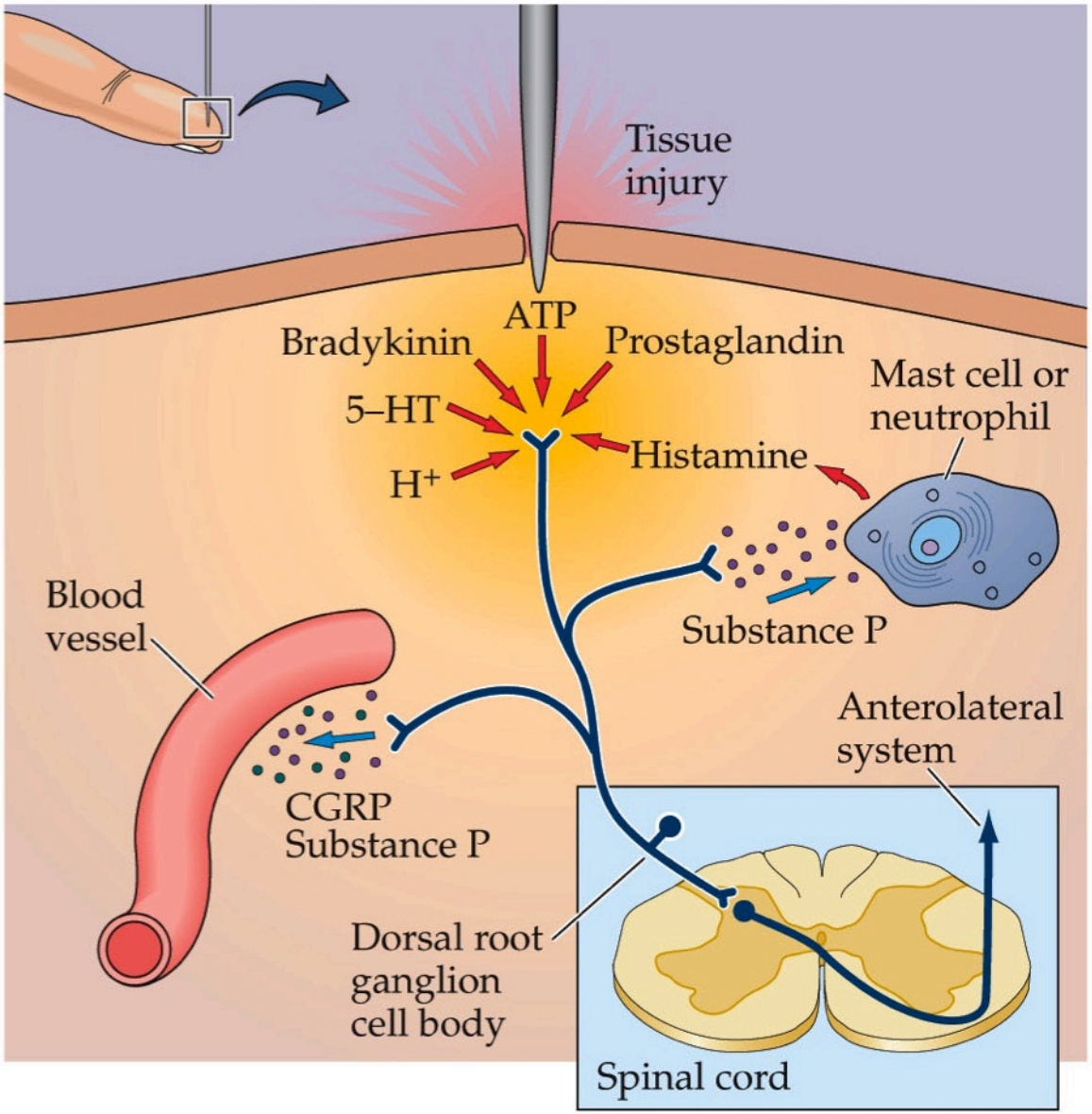






Pain

1) Response of normal receptors to extreme stimuli
2) Response of special nerve endings to injury signals



Proprioception