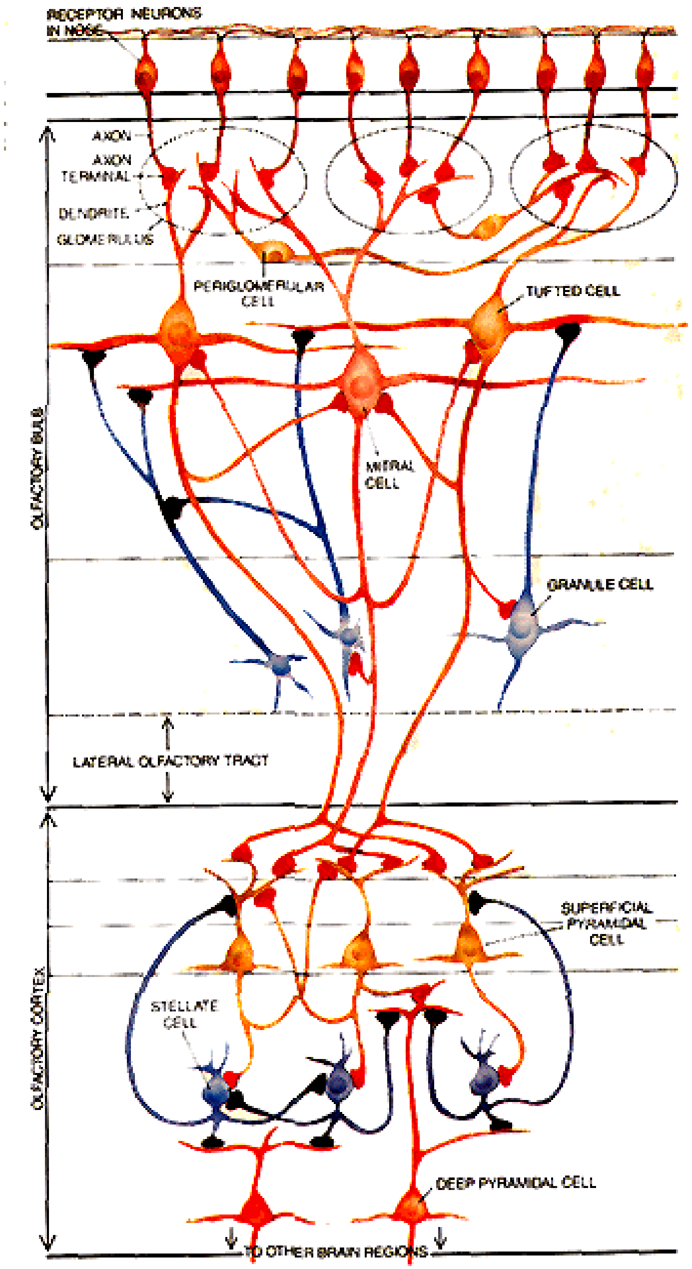


Walter J. Freeman, UC Berkeley

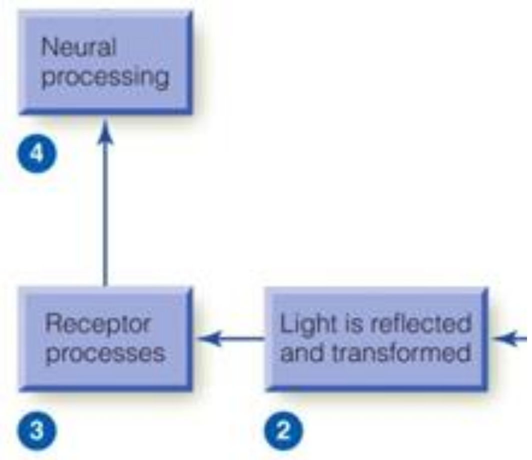
Sensory modularity and neuron fundamentals

10/17/14

Today

Basic wiring and organization of sensory circuits

- Finishing rod and cone differences
- Sensory modularity
- Neuron fundamentals
  - Action potentials and measurement
- Neural convergence and visual acuity

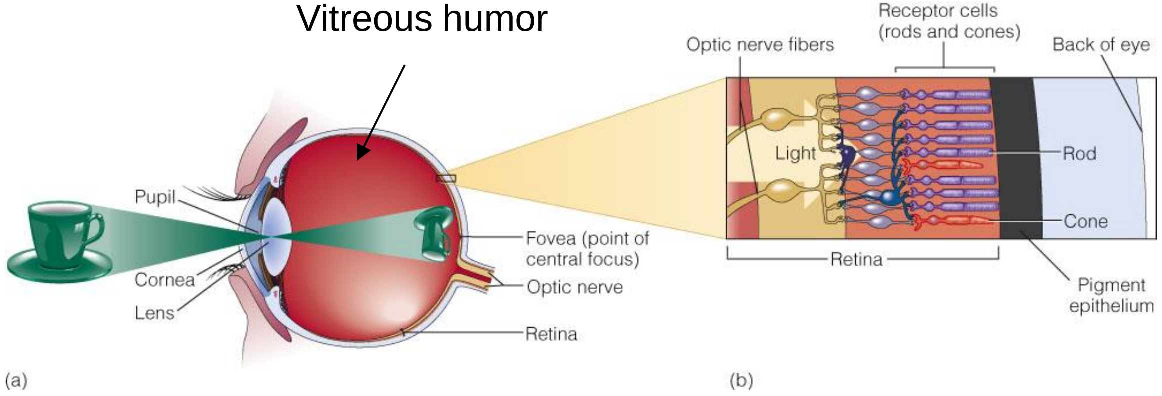


From earlier

Light reflects from objects and is transformed to become a pattern on the retina. Receptors change the light energy into neural energy through the process of transduction.

What happens from here?

Vitreous humor



From earlier

<u>Memory check</u>

Based on dark-adapted sensitivity experiments using the method of adjustment, what kind of receptors was found to have the *lowest absolute threshold*.

A. Rods

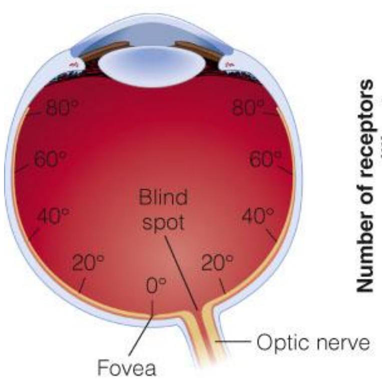
B. Cones

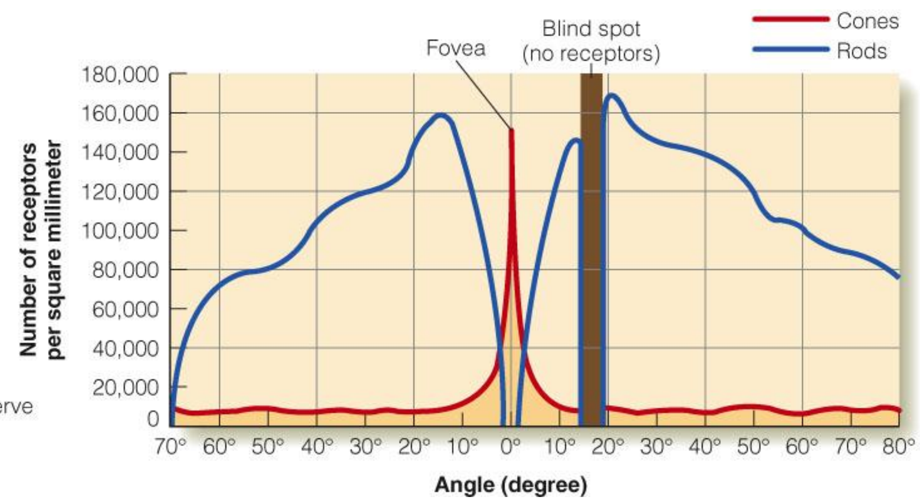
C. They are equally sensitive

Functional eye anatomy: rods & cones

Differences between rods and cones

- Distribution on retina
  - **Fovea** consists solely of cones (about 50,000 – 110,000).
  - Peripheral retina has both rods and cones.
  - More rods than cones in periphery.
- There are about 120 million rods and 6 million cones (though, this may be a high estimate).





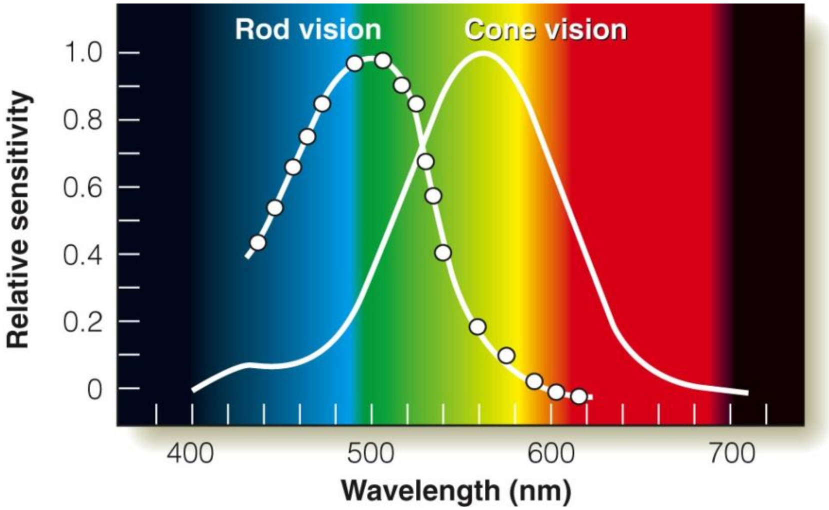
Functional eye anatomy: rods & cones

Rod spectral sensitivity:

- most responsive at ~500 nm.

Cone spectral sensitivity:

- most responsive at ~560 nm.



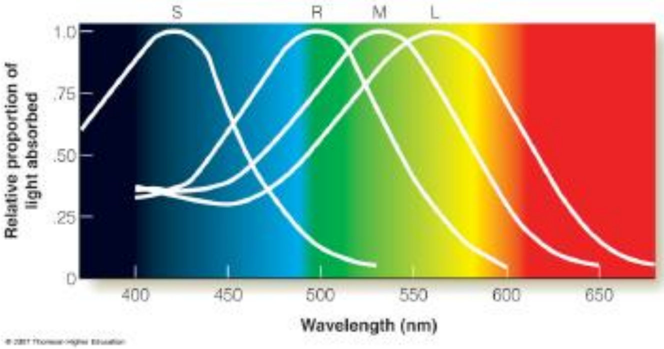
This difference results in the **Purkinje shift**, an enhanced sensitivity to shorter wavelengths during dark adaptation when the shift from cone to rod vision occurs.

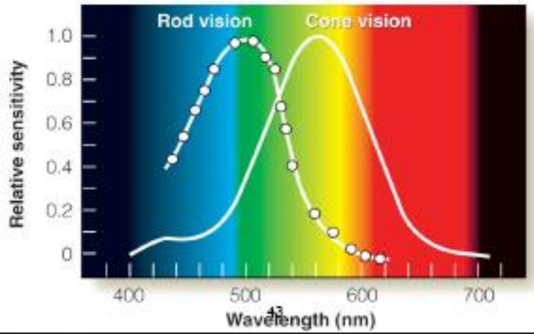
- Vision in daylight using cones is **photopic**.
- Vision at night using rods is **scotopic**.

Functional eye anatomy: rods & cones

Difference in spectral sensitivity is due to absorption spectra of visual pigments

- Rod pigment (R) absorbs best at 500 nm.
- Cone pigments absorb best at 419nm (S), 532nm (M), and 558nm (L).
- Absorption of all cones equals the peak of (approximately) 560nm in the spectral sensitivity curve

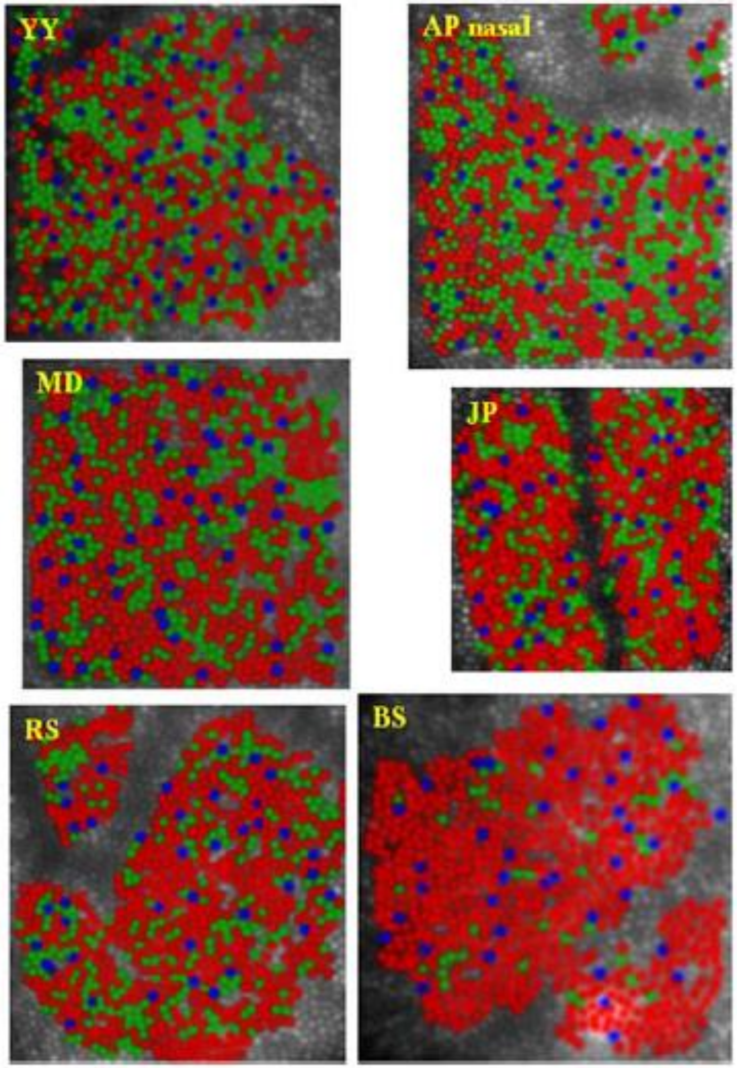




Functional eye anatomy: rods & cones

The number and placement of cone subtypes can vary greatly.

- L-cones are most numerous.
- Typically S-cones are the fewest in number (and least responsive).
- Distribution and number varies between people.
- Even in the same person, the cone types may vary across the retina.
- All subjects (in figure) have normal color vision.



Hofer et al. (2005)

Functional eye anatomy: rods & cones

Progress check

In brightly lit conditions, which visual receptors seem to be most *functionally sensitive*?

A. Rods

B. Cones

C. They are equally sensitive

What is sensory modularity?

Modularity is the idea that specific areas (modules) of the brain are specialized to process certain types of information or perform certain functions.

Sensory modularity suggests that specific brain regions are responsible for processing certain types of sensory information.

- The sensory information should be (initially) processed *independently* from other senses (no mixing).
- We should be able to find *specific neural circuits* that carry this information.

Where does this idea come from?

Sensory modularity

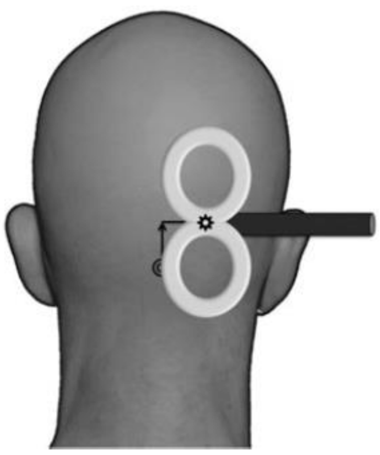
Doctrine of specific nerve energies

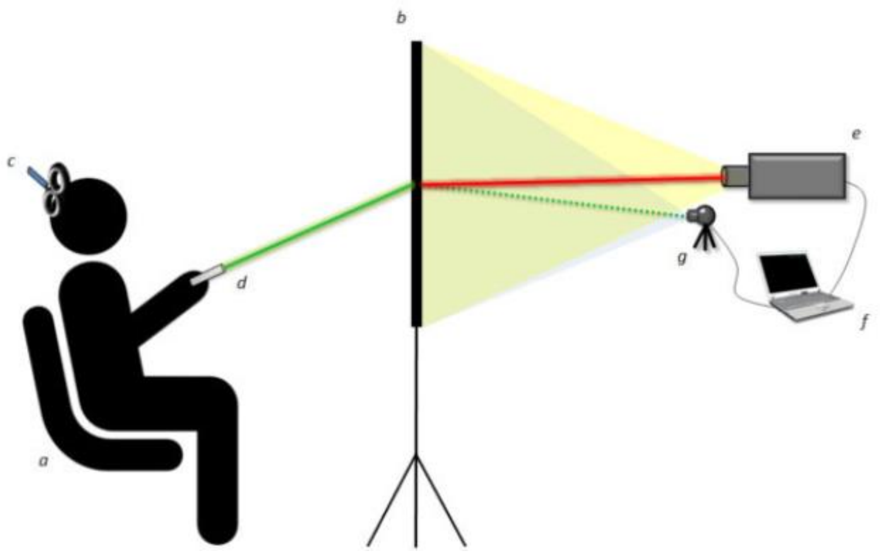
- Johannes Müller, in 1842, proposed that perception is based on the “nerve energies” received in the brain.
- This suggested that specific perceptions and their qualities/features depended on which neurons were stimulated.
  - So, it wasn’t the (distal) stimulus per se, but rather the activation of the neuron (by any means necessary) that was responsible for the sensation.
- This was one of the earliest examples of separating brain responses by discrete neural function.
- Later made more specific, stating that the activation of the target area in cortex was the critical element of the sensory experience.

Sensory modularity

Transcranial Magnetic Stimulation

Rapidly changing magnetic field induce electric current in cortical neurons. If done over the occipital cortex, it may induce **phosphenes** – perceived as flashes of light that appear in space.



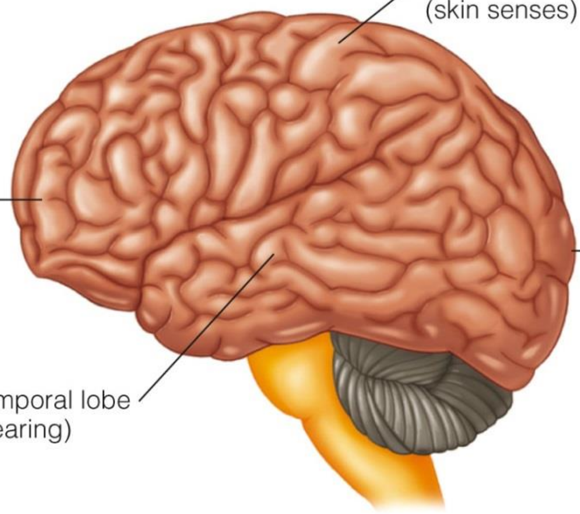


Elkin-Frankston *et al* (2010)

Basic sensory modularity in the cortex

The sensory modalities have primary receiving areas (targets) in the cortex:

- Vision – Occipital lobe
- Audition – Temporal lobe
- Touch – Parietal lobe
- Smell – Piriform cortex
- Taste – Insula and operculum



How do the signals get to the primary areas and how are they organized?

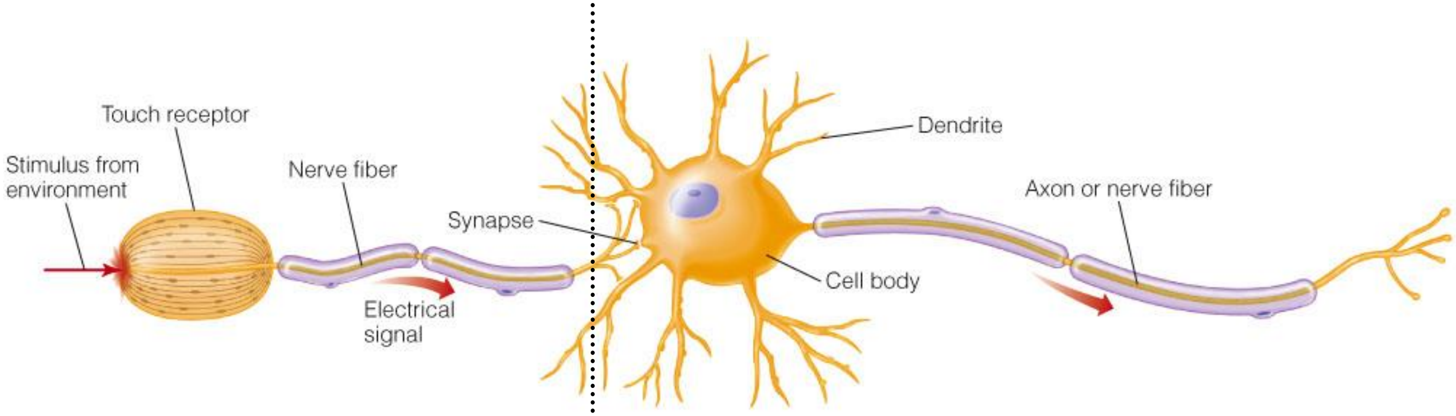
(Are they really modular?)

Sensory modularity

According to the **neuron doctrine,** the neuron is the basic cellular unit for processing information.

Basic structure of neurons:

- Cell body (Soma)
- Dendrites
- Axon (or nerve fiber)

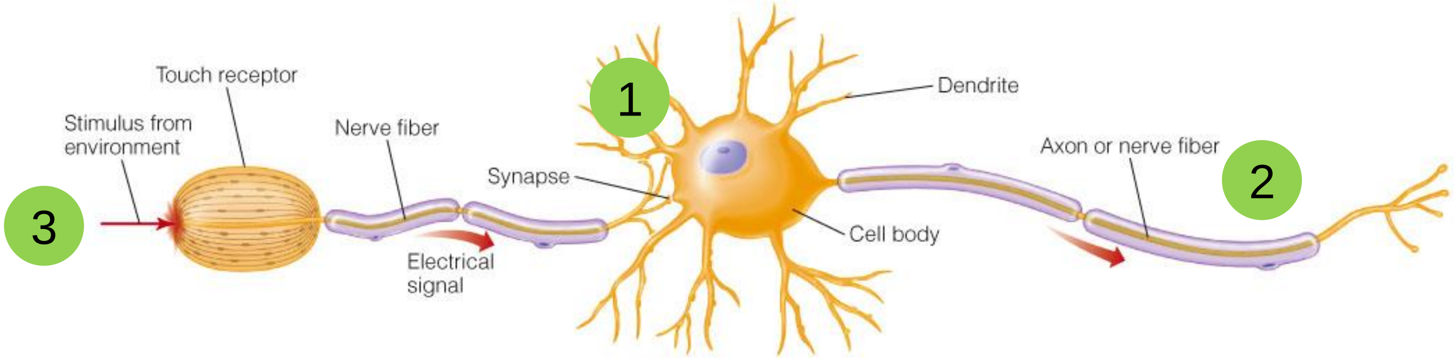


Unipolar neuron **Multipolar neuron**

Sensory modularity

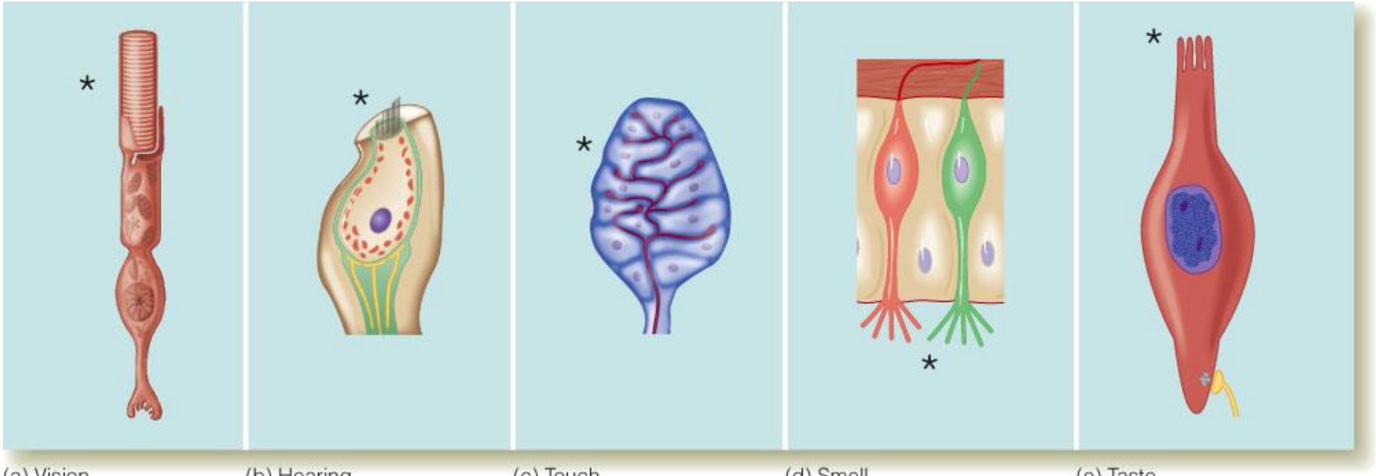
Neuronal activity can be causally triggered by three sources:

1. Chemical signals (e.g. neurotransmitters)
2. Electrical signals (e.g. action potentials, gap junctions)
3. Environmental signals



Sensory modularity

Receptors are specialized neurons that respond to specific kinds of **environmental** energy. We will see later how each of these detect specific elements/dimensions of the sensory environment.

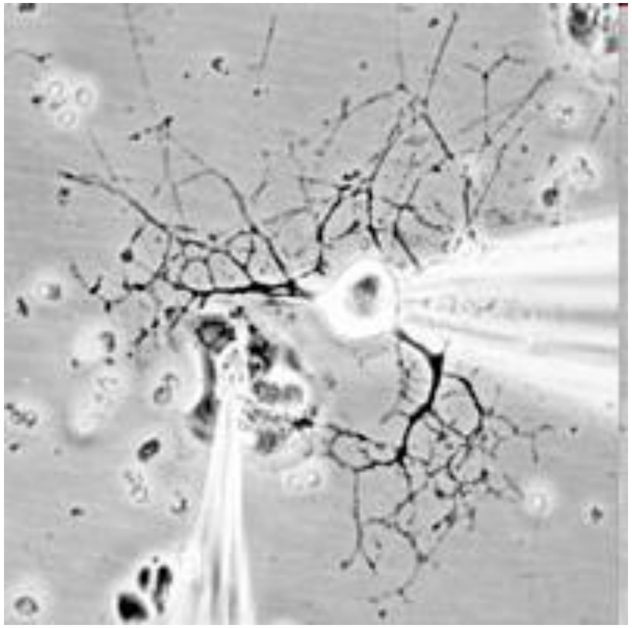


(a) Vision (b) Hearing (c) Touch (d) Smell (e) Taste

How do we measure specific neural signals?

Microelectrodes are used to record from single neurons.

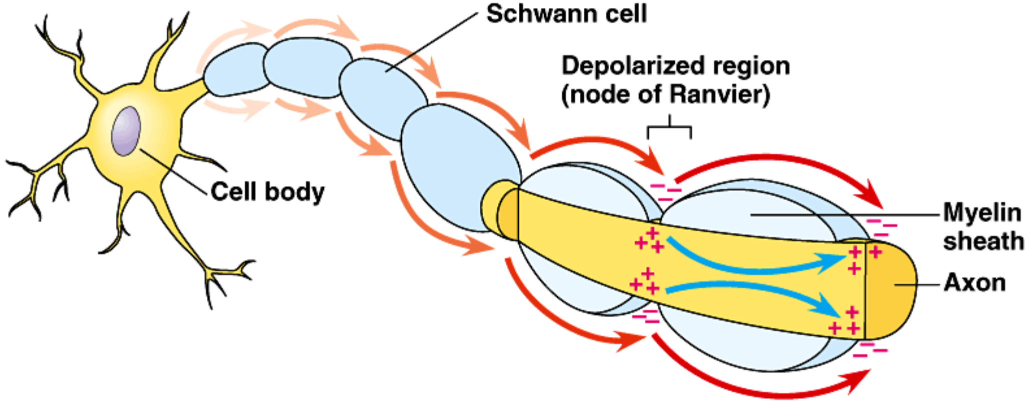
- This technique is called **single-unit recording**.
- Microelectrodes are made of pulled glass (or metal) with a conductive solution inside.
- Recording electrode is inside the nerve fiber (axon).
- Reference electrode is placed <u>outside</u> the fiber.
- Difference in charge between them is (typically) -70 mV
- This negative charge of the neuron relative to its surroundings is the **resting potential**.



S.P. Cook, E.W. McCleskey, *Pain,* 2002

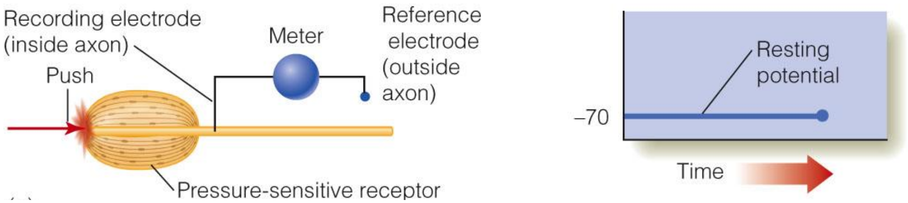
Measuring neural signals

Action potentials are the primary means of transmitting signals to other neurons. They are the voltage changes that travel the length of the neuron to the terminal button, where a **neurotransmitter** is released – *possibly* causing an action potential in the next neuron(s).



Measuring neural signals

Signal propagation

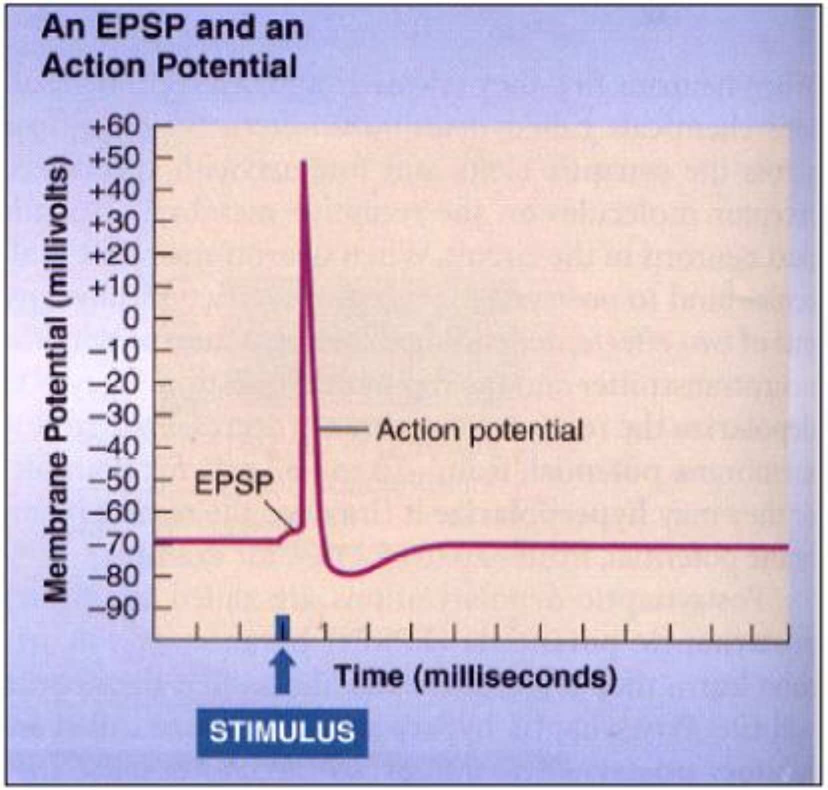


Action
Potential
Spike

Measuring neural signals

The action potential

- Actively propagated down the axon.
- Will fire **spontaneously** without stimulation (baseline rate).
- Remains the same size, regardless of intensity.
- Increasing signal intensity can increase the <u>rate</u> of firing.

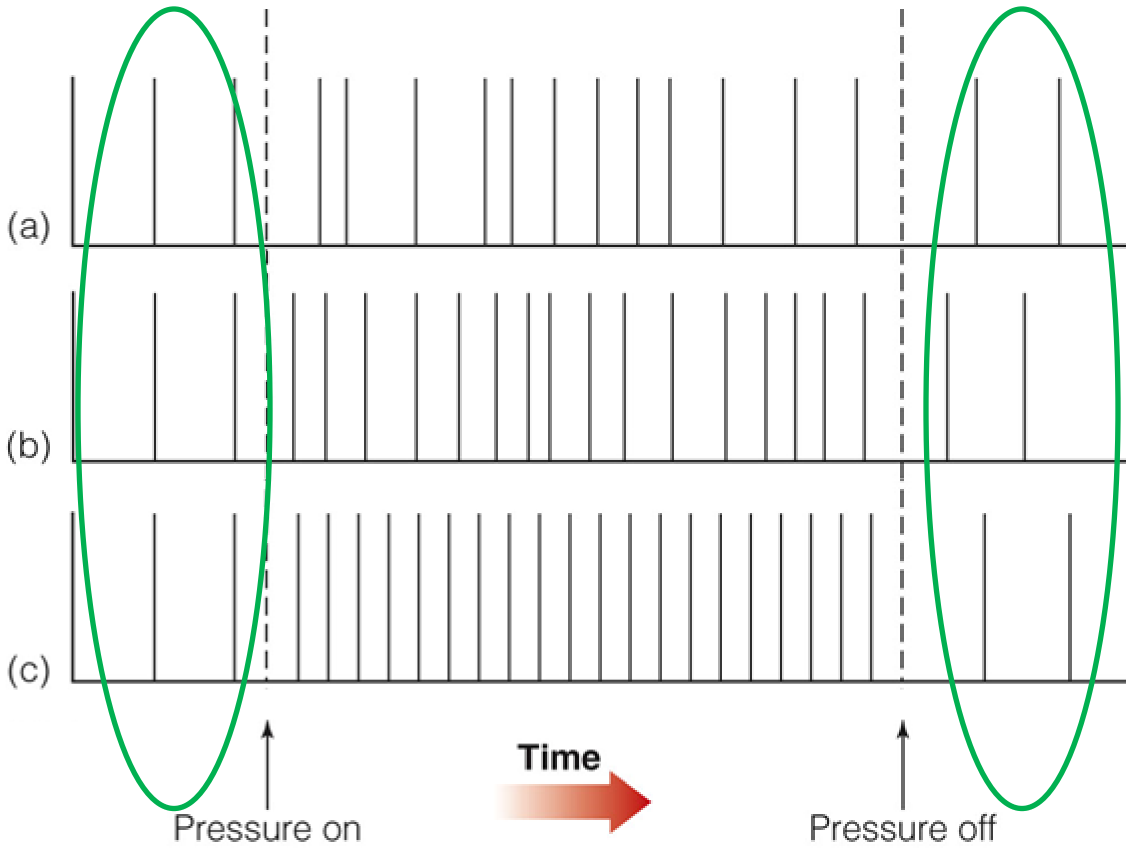


Measuring neural signals

Low intensity

Medium intensity

High intensity

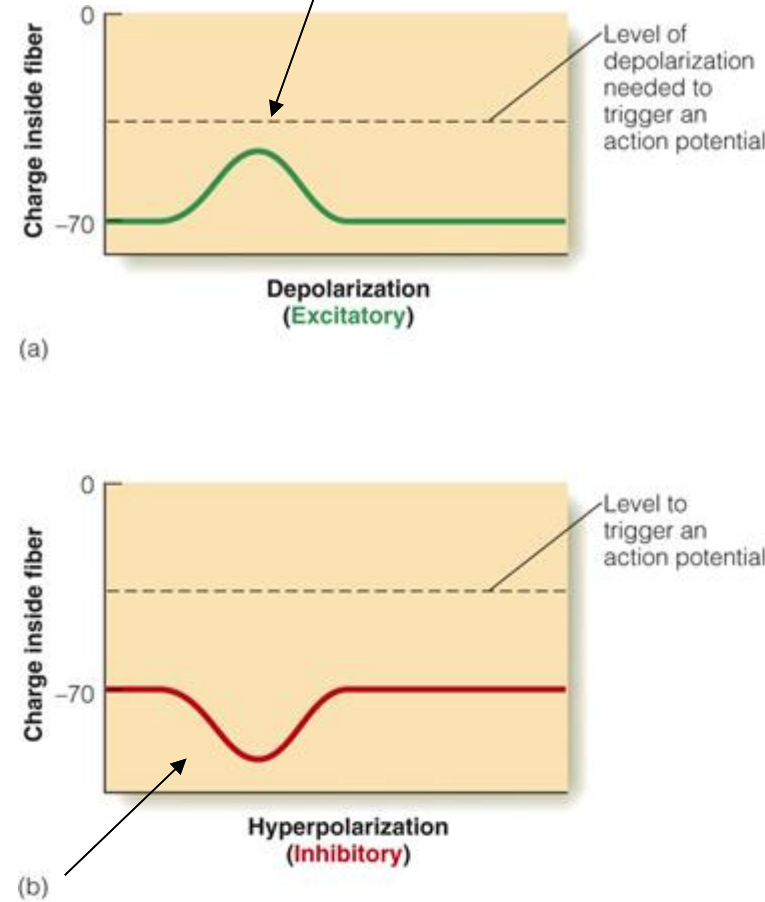


From neuron to neuron

When neurotransmitter binds to a receptor, ion channels open.

- An *influx* of positively charged ions (e.g. Na+) pushes the neuron toward <u>depolarization</u>
  - This is called an excitatory post-synaptic potential (**EPSP**)
- An *efflux* of positively charged ions (e.g. K+) makes the neuron more polarized (<u>hyperpolarized</u>)
  - This is called an inhibitory post-synaptic potential (**IPSP**)

Closer to threshold of excitation

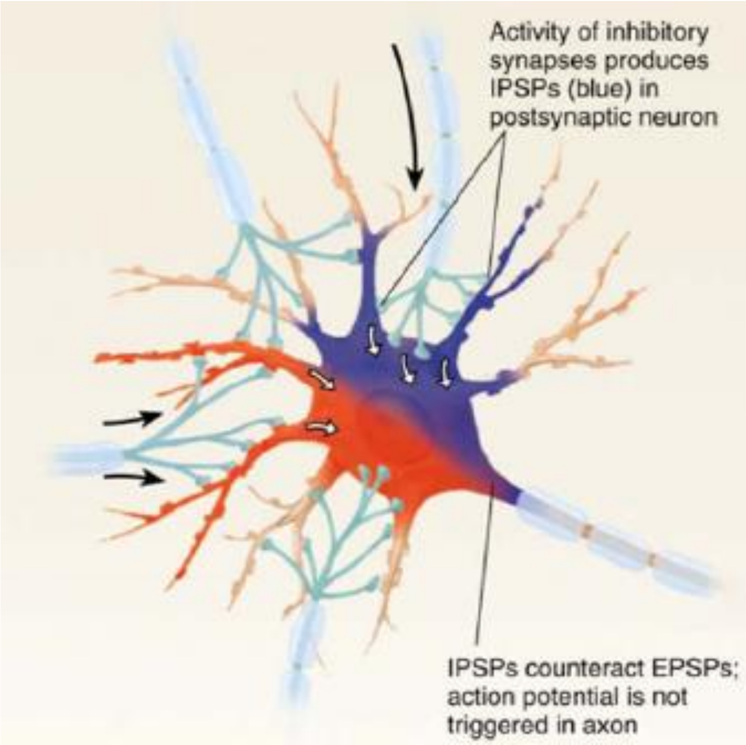


Farther from threshold of excitation

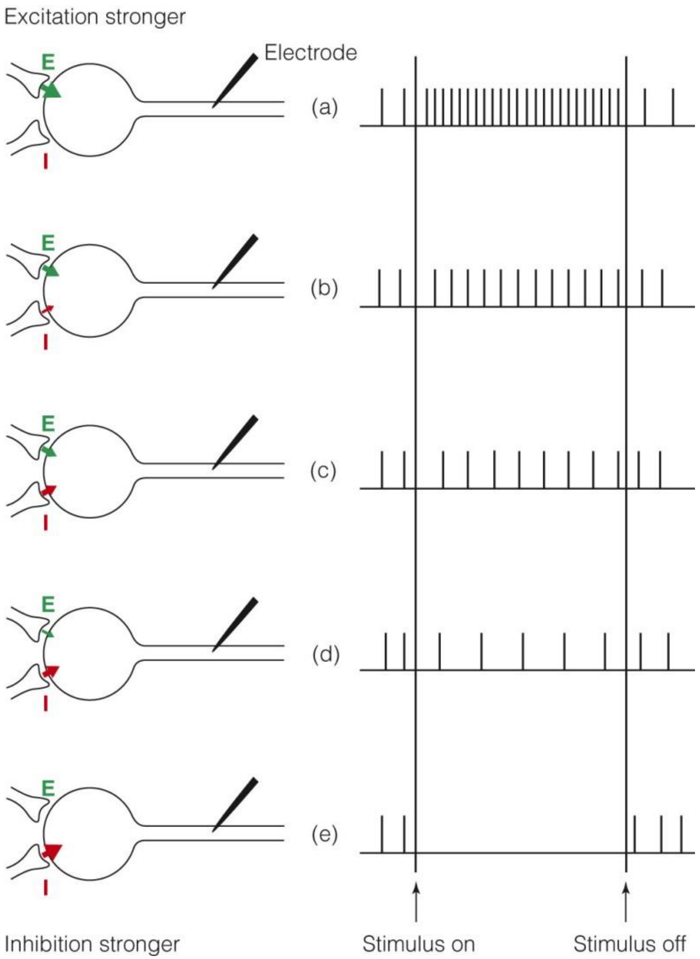
From neuron to neuron

EPSPs and IPSPs can summate on the same neuron.

An action potential is only triggered if the EPSPs can push the neuron to depolarization faster than the IPSPs pull it toward hyperpolarization.



Measuring neural signals



When excitation is stronger, you get more action potentials.

When inhibition is stronger, you get fewer action potentials, to the point of going below the spontaneous resting rate.

Measuring neural signals

Progress check

In a typical neuron, what specific kind of signal will drive the resting potential farther from the threshold of excitation?

A. IPSP

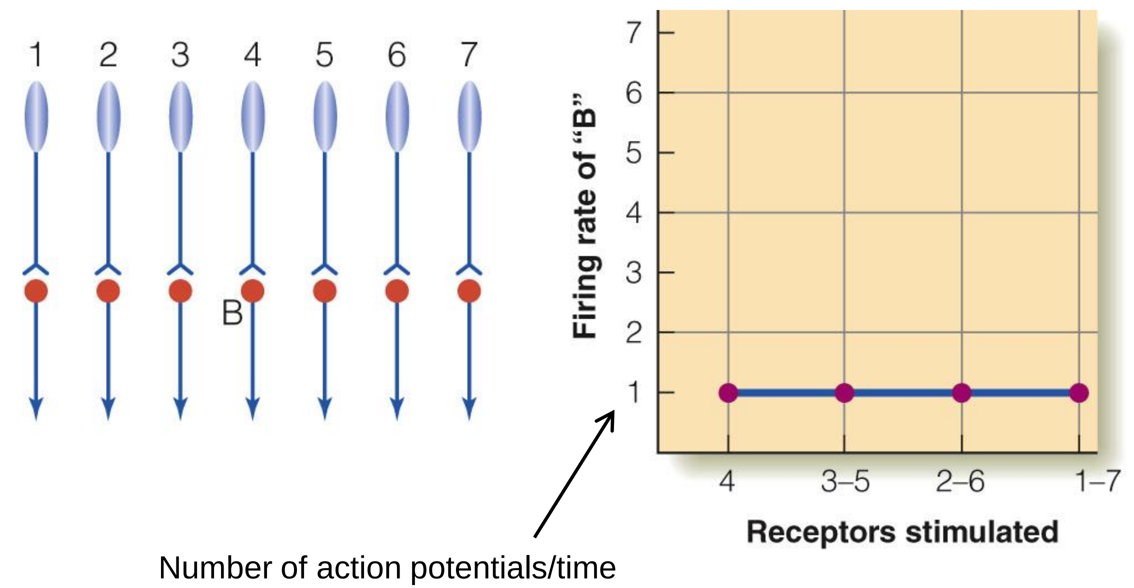
B. EPSP

C. Action potential

D. Depolarizing potential

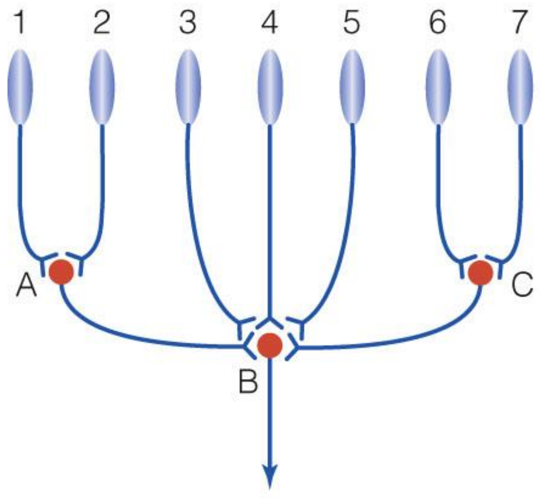
Forming a neural circuit

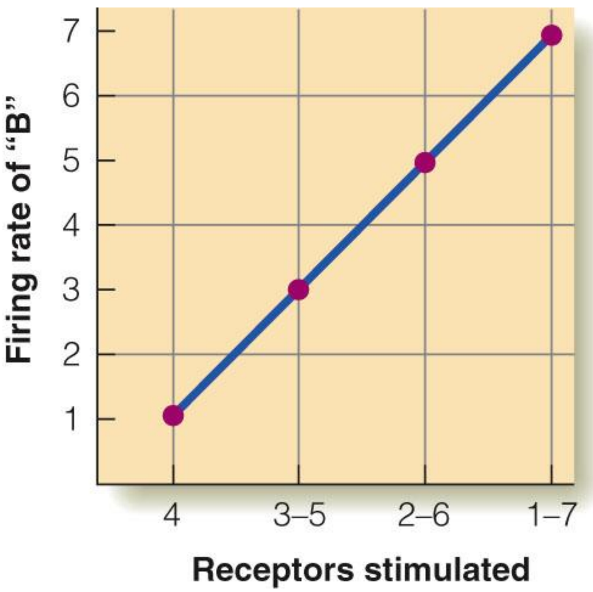
When neurons fire together as the result of stimulation, they form a **neural circuit**. The simplest circuits are made of isolated pairs of excitatory neurons.



Forming a neural circuit

More complex circuits are formed through **convergence** of synapses onto a single cell. The example below is purely excitatory.





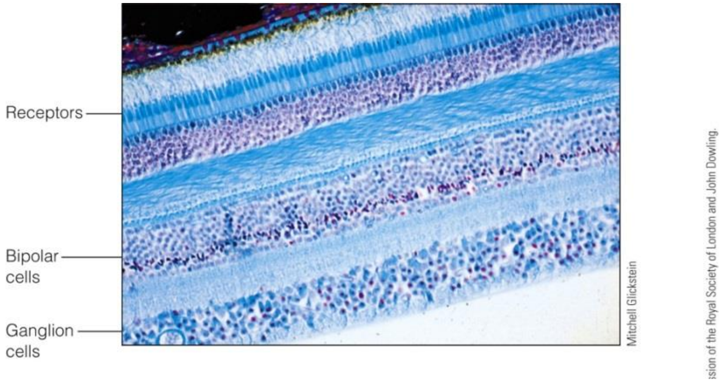
Neural convergence

Rods and cones send signals vertically through:

- **bipolar** cells
- ganglion cells

Signals are sent horizontally:

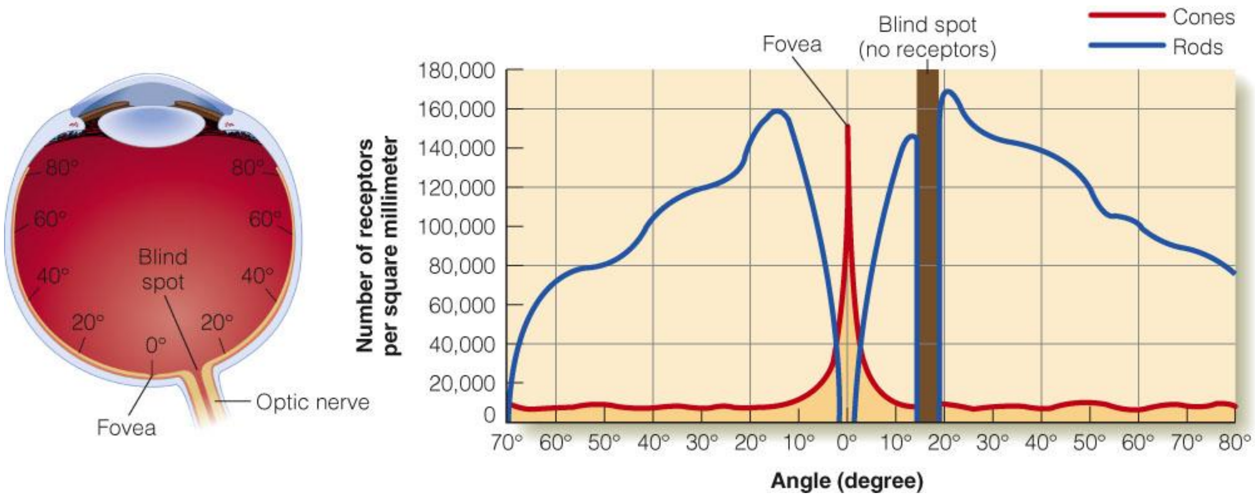
- between receptors by horizontal cells
- between bipolar and ganglion cells by **amacrine** cells.



From earlier

Differences between rods and cones

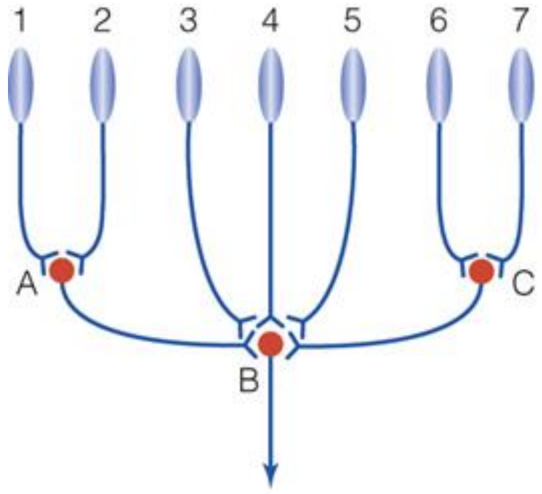
- Distribution on retina
  - **Fovea** consists solely of cones (about 50,000 – 110,000).
  - Peripheral retina has both rods and cones.
  - More rods than cones in periphery.
- There are about 120 million rods and 6 million cones



Neural convergence

How do retinal cells converge?

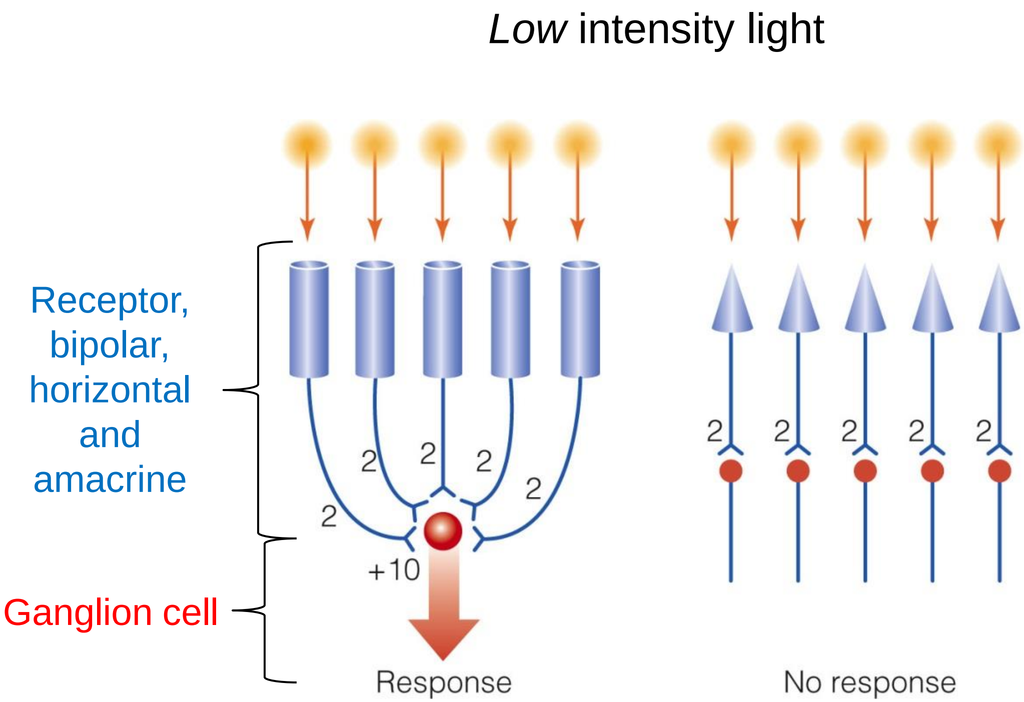
- 126 million rods and cones **converge** onto 1 million ganglion cells in each eye.
- Higher convergence of rods than cones
  - Average of 120 rods to one ganglion cell
  - Average of 6 cones to one ganglion cell
  - *Cones in fovea* have one-to-one relation to ganglion cells



Neural convergence

Rods are more sensitive to light than cones

- Rods take less light to respond.
- Rods have greater convergence which results in summation of the inputs of many rods onto ganglion cells, increasing the likelihood of response.
- Trade-off is that rods cannot distinguish detail.

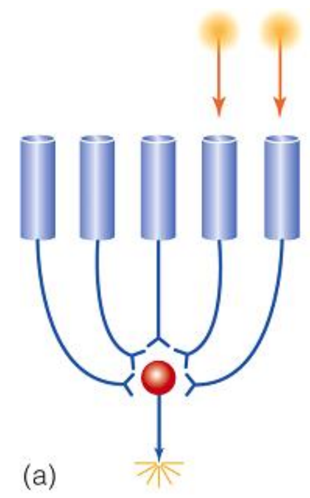


Neural convergence

All-cone vision in fovea results in high visual acuity.

- One-to-one wiring leads to ability to discriminate fine details.
- However, cones need more light to respond than rods.

High intensity light



"see one light"

Summary: Sensory modularity and organization

Basic wiring of the sensory brain

- Sensory processing is modular at the level of receptors, but perception depends on the area of cortex activated.
- Environmental energy can drive neural circuits.
- We can measure this (rate of) activity with microelectrodes.
- Patterns of activity and neural convergence will determine our sensory experience of the stimulus.

Next time

- Read chapter 3