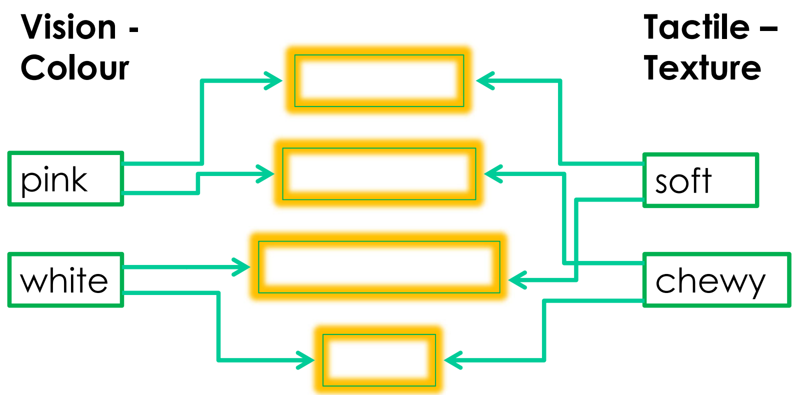
PHSL2101 - PHSL2121 – PHSL2501 Dr Richard Vickery
Neurophysiology 4 – Convergence and Optics

Objectives

- Describe convergence, divergence and spatial summation in central neural pathways. Give an example of an emergent neural property.
- Explain topographic organization and somatotopy, tonotopy and visuotopy.
- Describe the contribution of the various parts of the eye to image formation on the retina.
- Describe myopia, hyperopia and presbyopia and the lenses used to correct them.

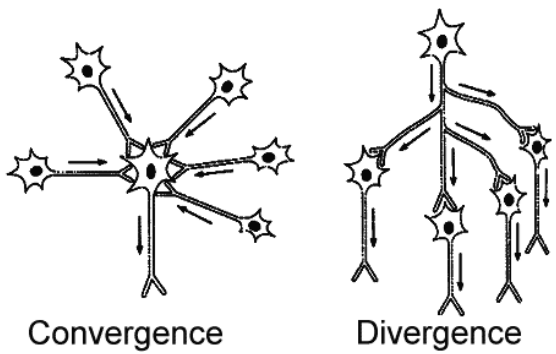
Convergence & divergence

New properties emerge when inputs converge…



Convergence & divergence

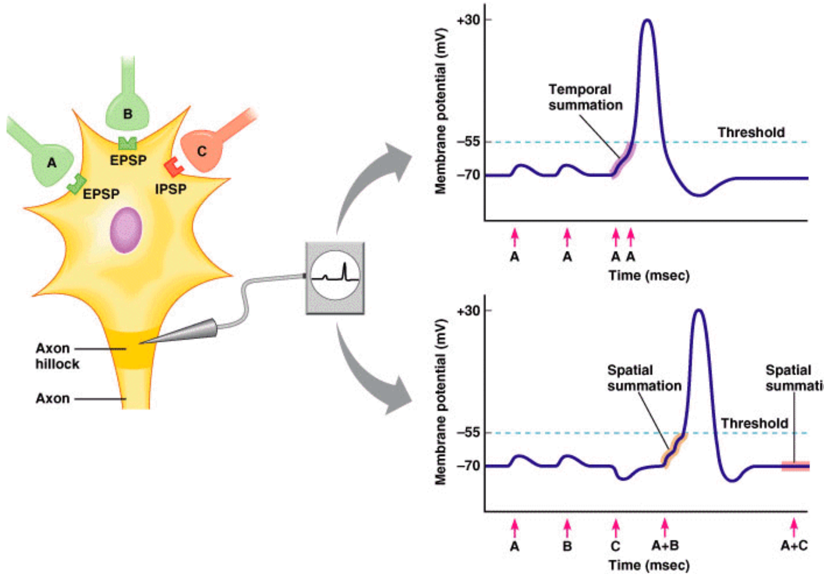
Neural processing requires convergence and divergence



There are thought to be ~10^{11} neurons in the CNS and ~10^{14} synapses. This implies that on average, each neuron makes 1000 synapses with, and receives 1000 synapses from, other neurons. The number for a given neuron can vary from 1 up to ~250 000.

Convergence & divergence

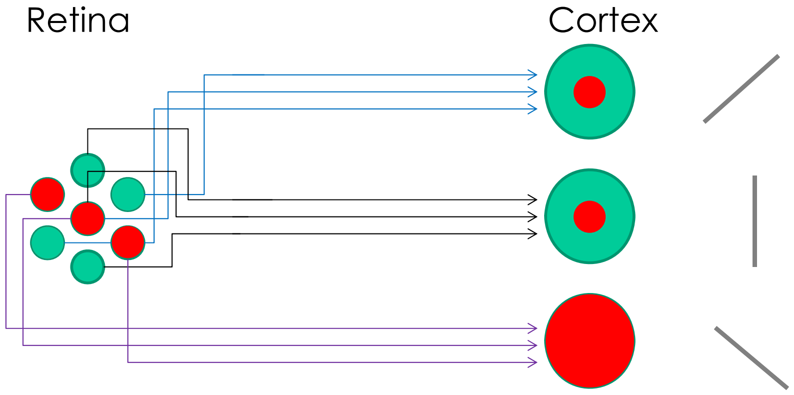
Convergence allows for spatial summation which can support integration of information



from Germann & Stanfield, Principles of Human Physiology

Convergence & divergence

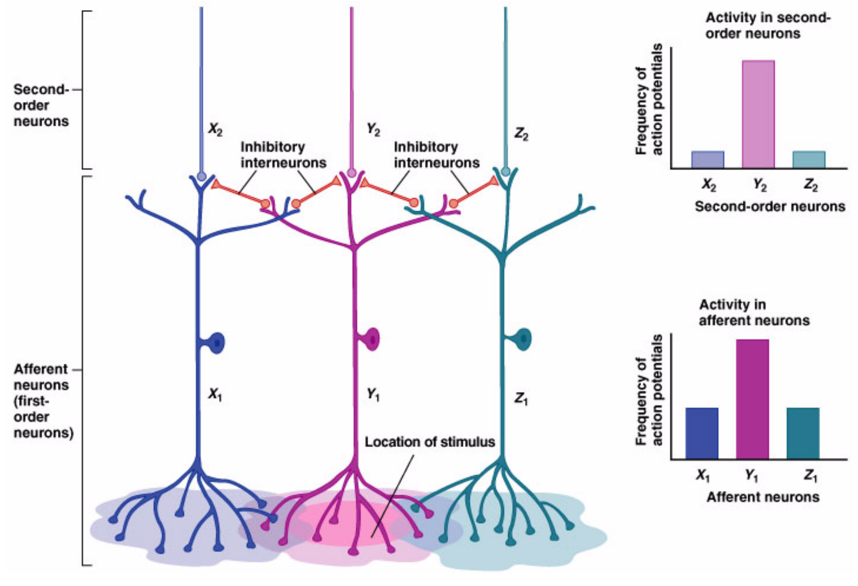
New properties emerge when inputs converge…



Orientation selective cells first appear in the visual system at the level of primary visual cortex. They respond to selective convergent input that makes them sensitive to a particular line orientation, even though the retinal ganglion cells do not detect orientation.

Convergence & divergence

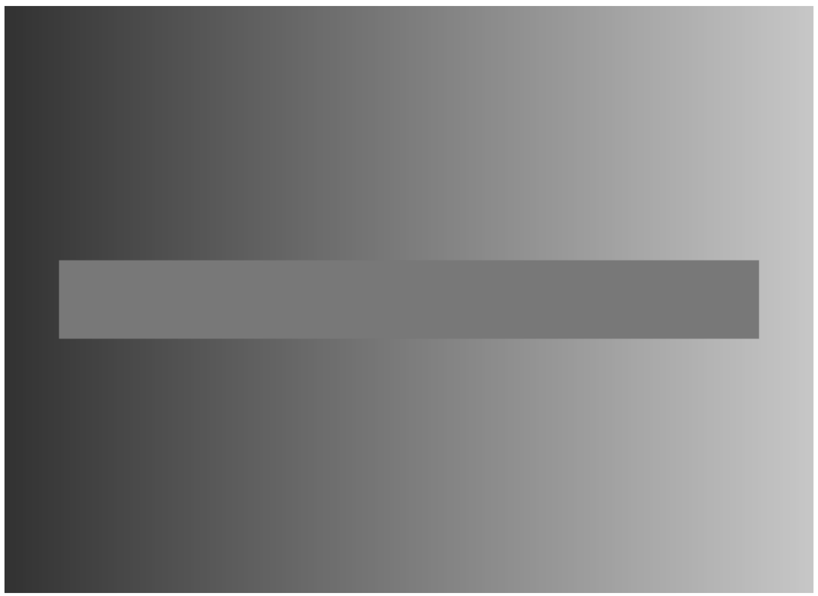
Lateral inhibition "sharpens" inputs and constrains divergence



from Germann & Stanfield, Principles of Human Physiology

Convergence & divergence

Lateral inhibition alters our perception of the real environment



from Wikipedia

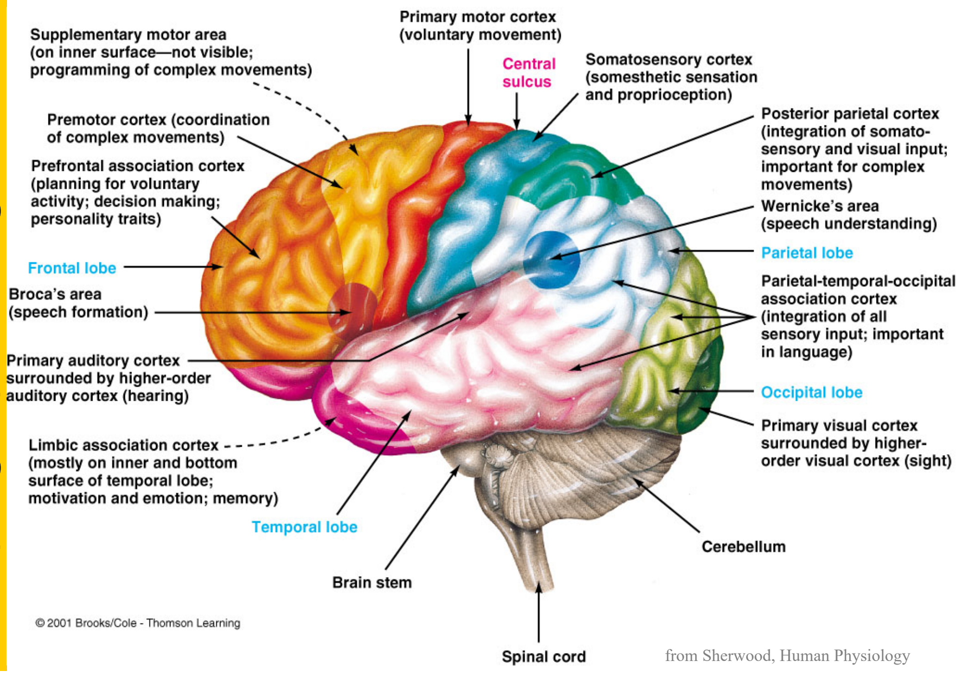
Convergence & divergence

Convergence and divergence

- Convergence of information allows higher neurons to integrate information from their input neurons.
- Decision-making implies that a given input can give rise to different outcomes. This requires divergence of the input, so that it goes to neurons that produce the different outcomes.
- Neurons in the CNS need simultaneous inputs from many synapses for them to reach their excitatory threshold and generate an action potential. This is called spatial summation. This is different to the neuromuscular junction, where the synapse from one motor neuron can reliably generate an action potential in the muscle.
- The pattern of diverging connections is precise: generally keeping different modalities separate on the way to cortex, as well as preserving the location signal.
- Lateral inhibition is a dynamic process, where the tendency of divergence to spread a sensory input over a large number of higher order neurons is opposed by inhibition driven by the same input.

Topographic organization

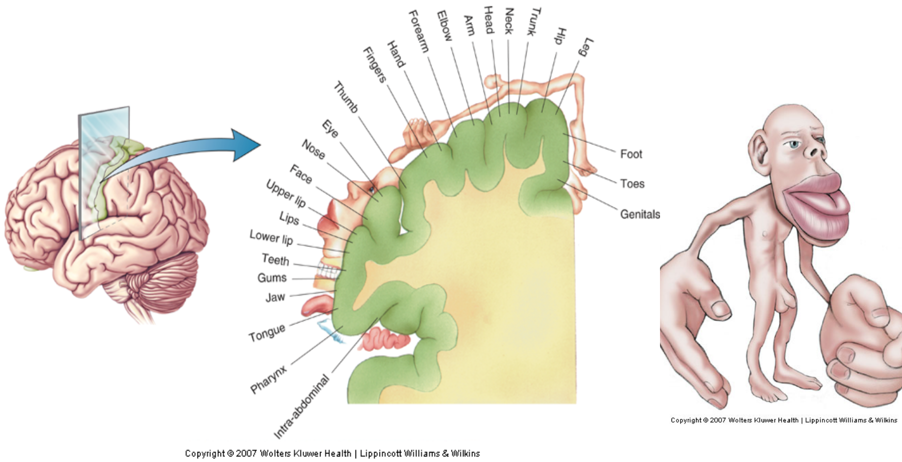
Organization of sensory cortex



from Sherwood, Human Physiology

Topographic organization

Somatotopy and the homunculus

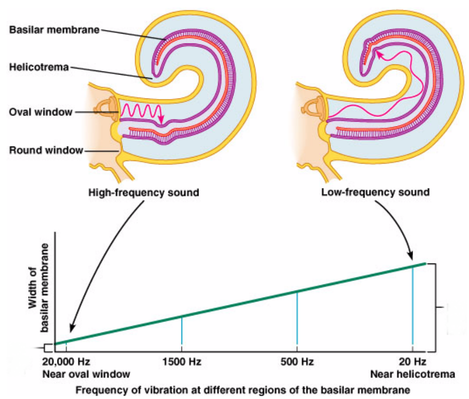


Cortical organization that preserves the local relationship of afferents is called *topographic organization*: peripheral neighbours remain cortical neighbours. For the body map this is called **somatotopy.** Cortical magnification shown in the homunculus reflects peripheral receptor density.

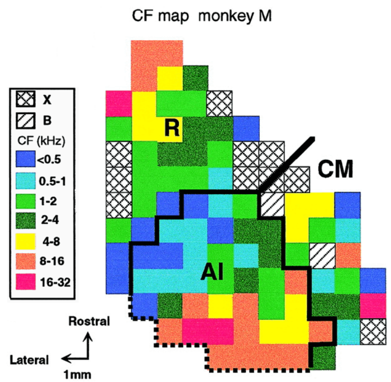
from Bear, Connors and Paradiso; Neuroscience: Exploring the Brain

Topographic organization

Auditory cortex has topographic organization called tonotopy



Cochlea has pitch organised linearly along the basilar membrane



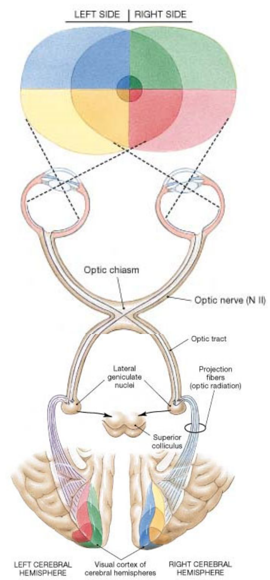
Cortex preserves this pitch-based organization.
AI is the primary auditory cortex.
CF (kHz) is the sound frequency that best activates this region of cortex

Recanzone et al., 2000; J. Neurophysiol. 83: 2315

from Germann & Stanfield, Principles of Human Physiology

Topographic organization

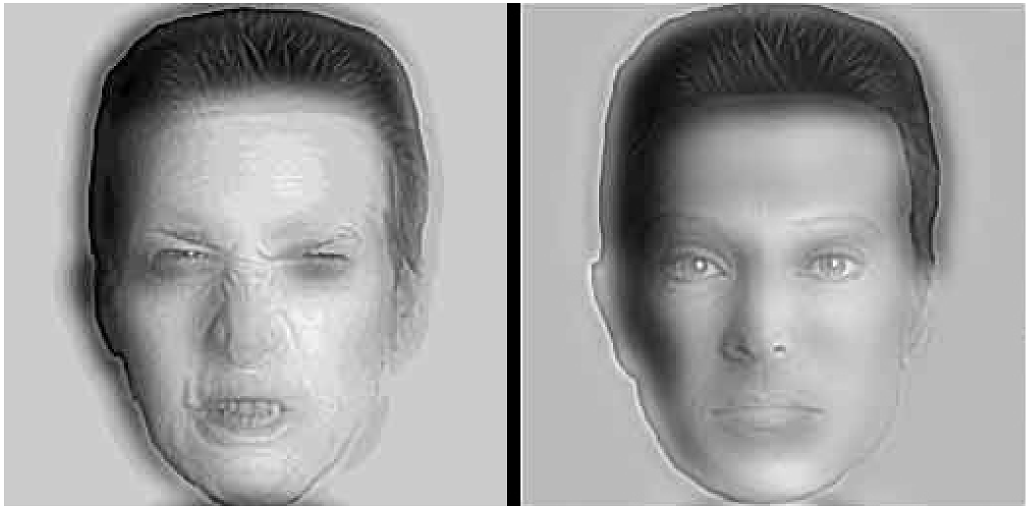
Visual topography is called visuotopy, and shows foveal magnification



Topographic organization

Topographic organization

- The core concept in topographic organization is that a sheet of neurons is one part of the nervous system maps to a sheet of neurons elsewhere in the nervous system.
- In sensory systems, one of these ‘sheets’ is usually the receptors. The receptor sheet can be the retina, the skin (for any of pain, touch, cold, warm), the cochlea. The receptor sheets map to cortex, but also to intermediate nuclei on the way such as in the thalamus.
- The basic mapping is hardwired, and then the detailed connections are tweaked based on activity in the connected neurons. Because of this the maps are not 100% precise, but are able to adapt to changes.



Optics

Job description for the eye

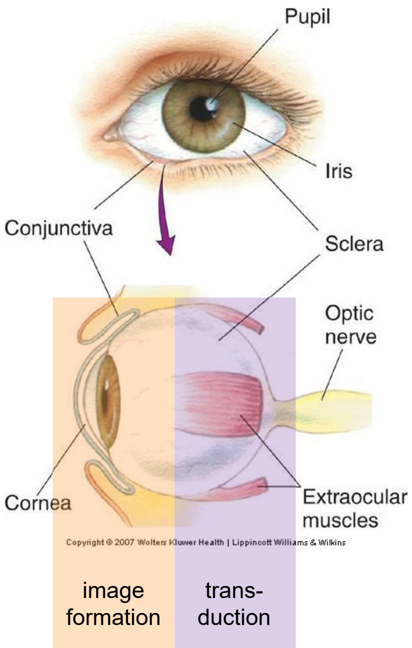


Image formation: objects in the environment emit or reflect light. The eye uses refraction to focus these light sources into an image on the back of the eye (the retina).

Transduction: the image on the retina must be converted from electromagnetic radiation into membrane depolarization. Properties such as frequency (colour), amplitude (brightness), and location must be encoded.

Optics

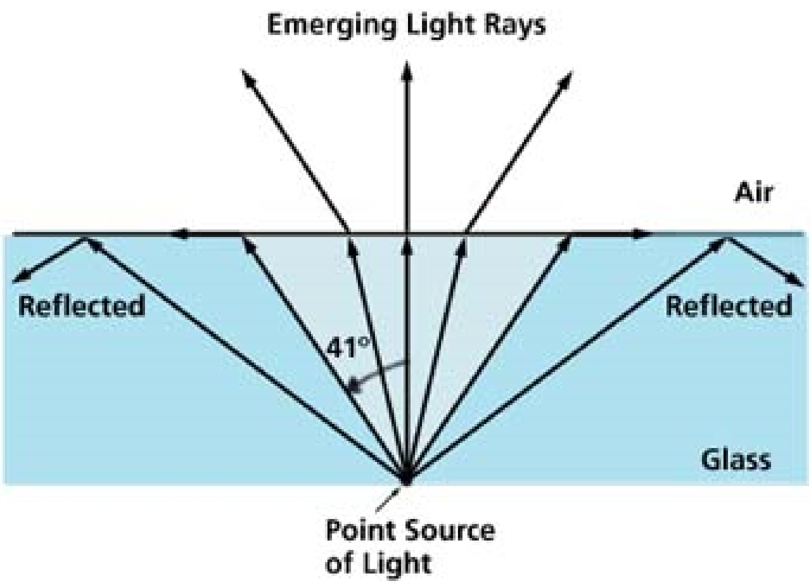
Refraction

Refractive index is the ratio of the speed of light in a vaccuum to the speed of light in the medium.
The refractive index of air is 1.00
The refractive index of water is 1.33 (at 25°C)

Refraction (not reflection) is the bending of light rays when they pass from one transparent medium to another.
The amount of bending increases with:
1) a larger difference in refractive index
2) an angle of incidence further from perpendicular

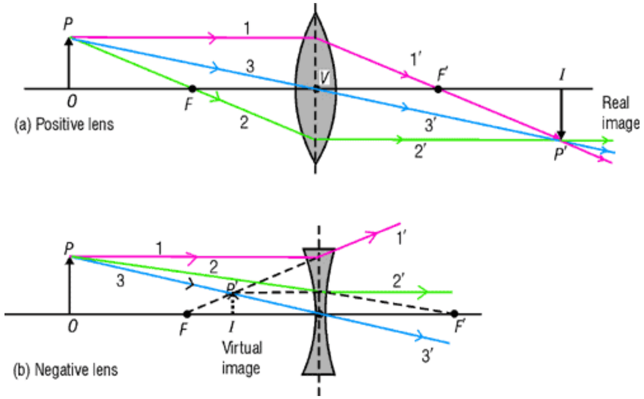
Optics

Refraction depends on the angle of incidence



Optics

A convex and a concave lens



Convex lenses converge rays emitted from a point, back to a point to form a real image.
Concave lenses diverge rays, and so are considered to form a virtual image.

Optics

Power of a lens

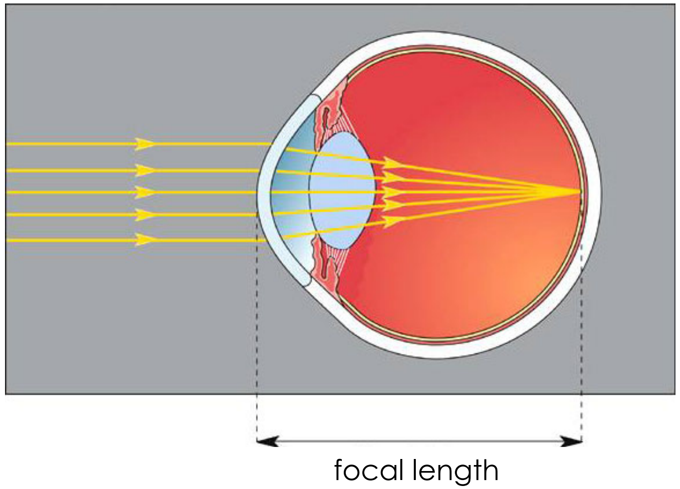
A convex lens converges light rays to a **focal point**. The distance between lens centre and focal point for incoming parallel light rays is the **focal length**. The reciprocal of the focal length measures the **power** of the lens (in diopters or D).

The power of a lens depends upon its
- radius of curvature
- the refractive index of the medium.

Concave lenses make parallel light rays diverge, and so the power of concave lenses is expressed in negative diopters.

Optics of the eye

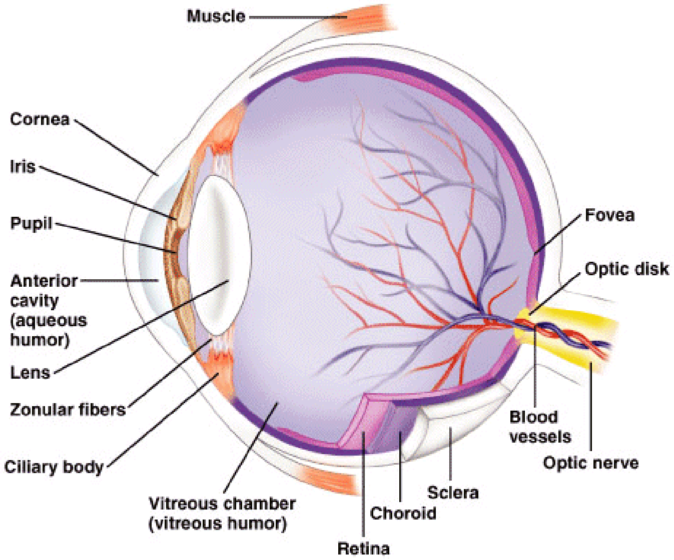
Focal length of the eye



focal length of the eye is 0.017m
Power = 1 / (focal length)
therefore Power = 1 / 0.017m = 58 D

Optics of the eye

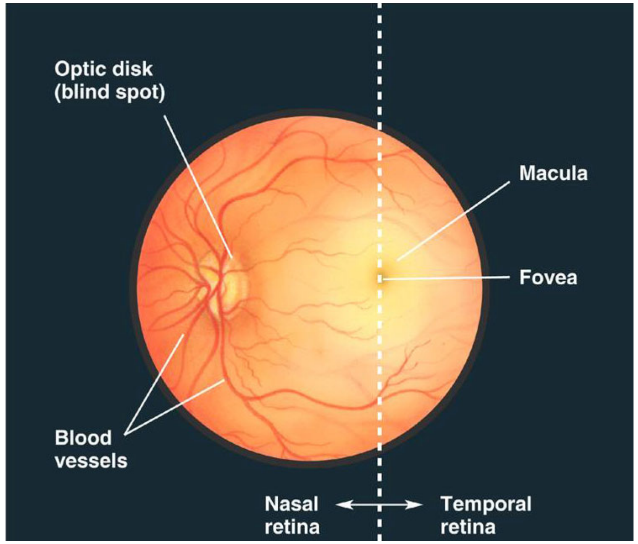
Structure of the eye



from Germann & Stanfield, Principles of Human Physiology

Optics of the eye

Retina seen through the pupil



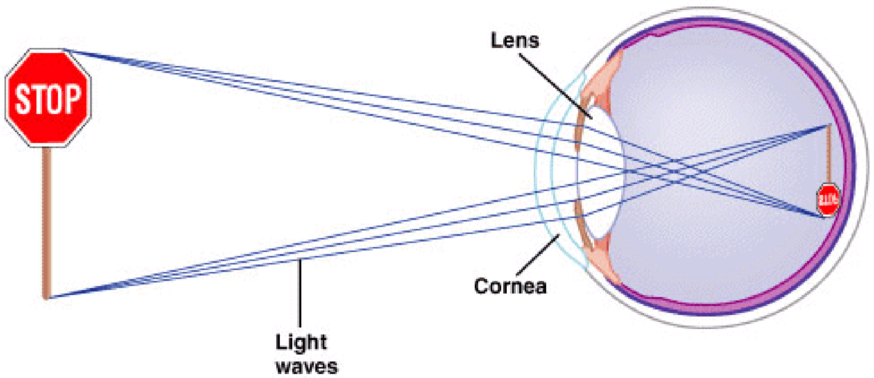
The **optic disk** produces the functional **blind spot**.

The **fovea** is where the image is centred.
There are few blood vessels in this area.

from Bear, Connor and Paradiso; Neuroscience: Exploring the Brain

Optics of the eye

The retinal image is inverted

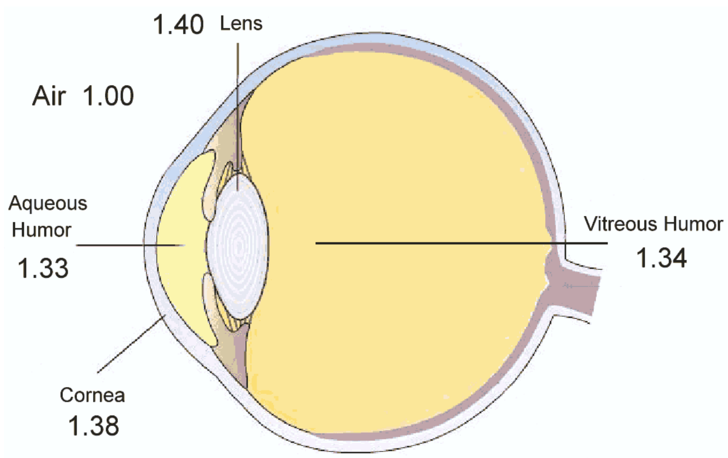


The inversion of the retinal image is of no significance to the brain, as it has never known any other orientation. The brain learns the mapping between stimulus and receptor.

from Germann & Stanfield, Principles of Human Physiology

Optics of the eye

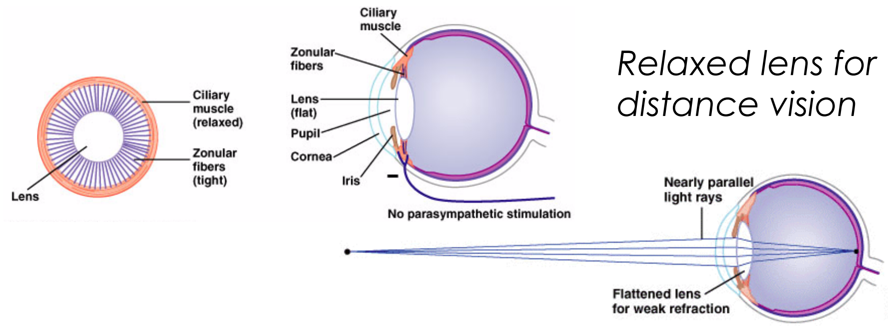
Refractive indices of parts of the eye



Although the lens has the higher refractive index, it is less powerful than the cornea because the **change in refractive index** is smaller.
Change at Cornea is 1.00 to 1.38; Lens is 1.33 to 1.40

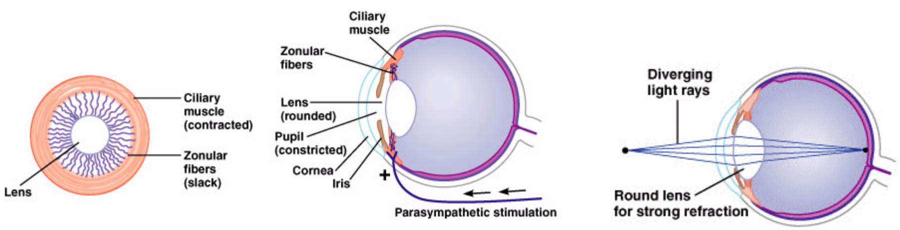
Optics of the eye

Accommodation for near vision



Relaxed lens for distance vision

Accommodated lens for near vision



from Germann & Stanfield, Principles of Human Physiology

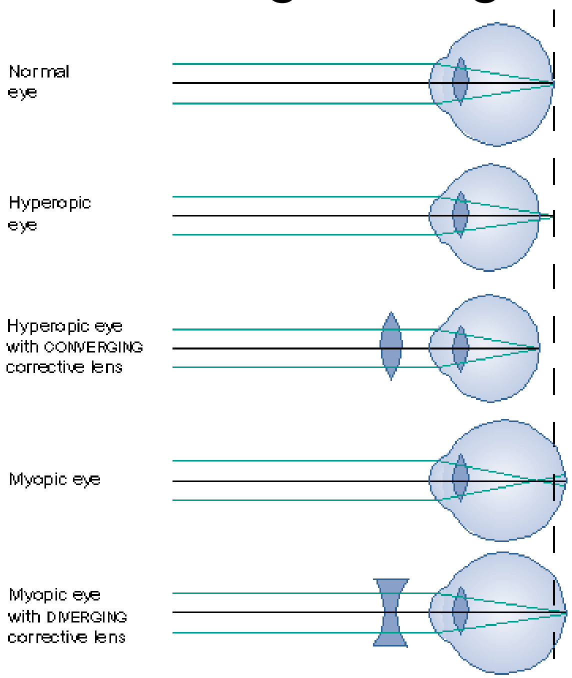
Correcting Optics

Accommodation of the lens allows us to vary the eye's focal length

- The power of the eye focused at infinity is 59 D, which equates to a focal length of 17 mm.
- Two thirds of the power is the air/cornea interface.
- A normal or **emmetropic** eye has objects at infinity in focus on the retina with the lens is relaxed.
- **Accommodation** increases the power of the eye to bring near objects into focus.
- In young people, accommodation can change the lens power by up to 14 D. **Presbyopia** is the decrease in accommodation with age as the lens becomes stiffer and loses elasticity.

Correcting Optics

Correcting for long and short sight



Hyperopia is also called **long sight**. It is not usually corrected unless severe, as the patient can use the accommodation of their lens to compensate. **Presbyopia** will ultimately require these people to use reading glasses.

Myopia is usually called **short sight**. It is due to the eye being too long, or a cornea that has too much power.

from Pocock & Richards, Human Physiology