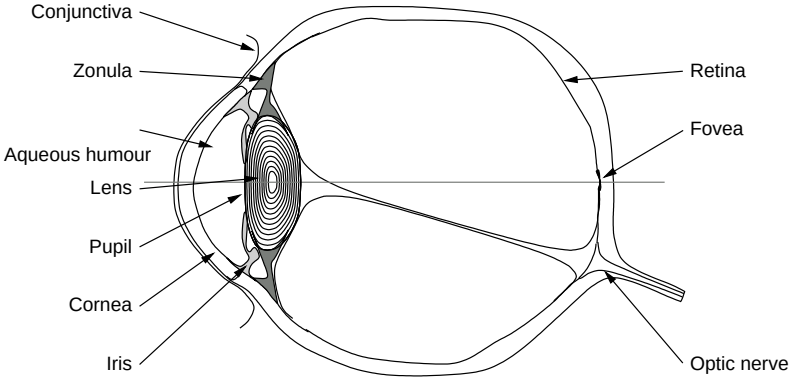
Statistics 120
Vision I

The Visual System

- The visual system consists of two parts.
  - The *eyes* act as image receptors.
  - The *brain* acts as an image processing and interpretation unit.
- Understanding how we see requires that we understand both components.

The Human Eye

(The Right Eye Viewed From Above)



Packaging

- The *sclera* is commonly known as “the white of the eye.” It is the tough, opaque tissue that serves as the eye’s protective outer coat.
- The *cornea* is the transparent, dome-shaped window covering the front of the eye. It is a powerful refracting surface, providing 2/3 of the eye’s focusing power.
- The *conjunctiva* is the thin, transparent tissue that covers the outer surface of the eye. It begins at the outer edge of the cornea, covering the visible part of the sclera, and lining the inside of the eyelids.

Focus Control

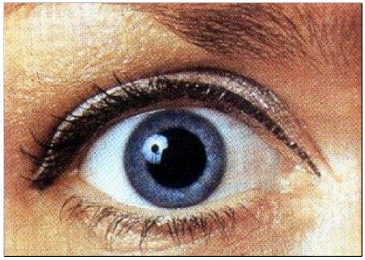
- The *cornea* and *aqueous humour* act as a primary lens which performs crude focusing of the incoming light.
- The *lens* is made of a soft transparent substance. It provides control over the eye's focusing.
- The *zonula* is a muscle which controls the shape and position of the eye's lens.
- With age, the lens gradually hardens making it harder for the eye to focus on nearby objects.

The Iris and Pupil

- The *iris* is a coloured muscle which covers all but a small opening in the font of the eye.
- The iris controls the amount of light entering the eye.
- The opening at the centre of the iris is called the *pupil*.
- In low-light the pupil dilates to let in more light.
- The size of the pupil is also subject to mood. The pupil dilates when we are happy or experiencing pleasure – this is why such times seem “brighter.”

Constricted and Dilated Pupils

Constricted



Dilated

The Interior of the Eye

- The *vitreous humour* fills the interior cavity of the eye, providing support.
- The *retina* provides a photosensitive layer on the inside of the eye.

The Retina

The retina is a layer of specialised nerve cells which line the eye and convert light into electrical signals.

- Many millions of individual photo receptors generate the electrical signals.
- Interconnecting horizontal cells combine and modify the signals.
- Ganglion cells conduct the signals to the brain.

Retinal Structure

- Receptor cells are at the back of the retina.
- Light passes “through the wiring”.
- Horizontal cells do some initial signal processing.

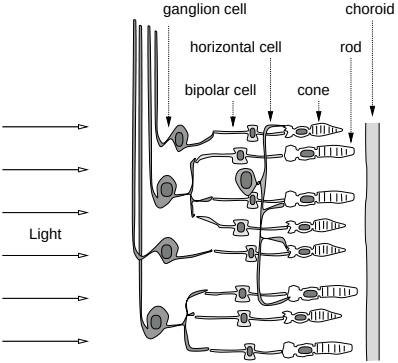
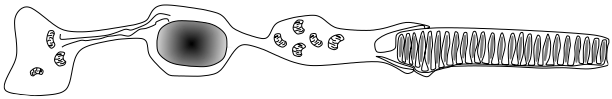


Photo Receptor Cells

- The eye contains two different classes of light sensitive cells (or photo receptors).
- *Rod cells* provide sensitive low-light vision.
- *Cone cells* provide normal vision.

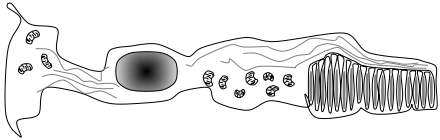
Rod Cells

- Rod cells provide low-light vision.
- There is only one type of rod cell.
- Rod cells provide no colour discrimination.



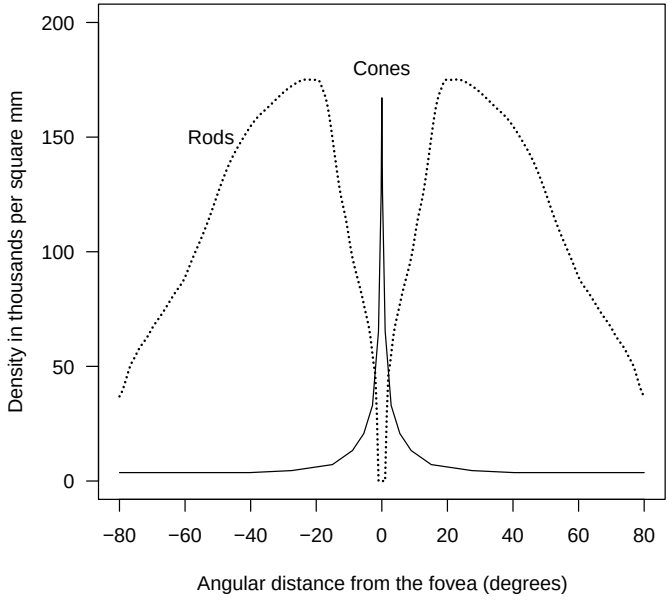
Cone Cells

- Cone cells operate at medium and high light levels.
- There are three different kinds of cone cells, each sensitive to different light wavelengths.
- The sensitivity to different wavelengths is what provides us with colour vision.



Rod And Cone Distribution

- The distribution of rod and cone cells is not uniform across the retina.
- The cones are concentrated at the centre rear of the retina and the rods are more evenly distributed away from that area.


The Distribution of Rod and Cone Cells
Density in thousands per square mm
200
150
100
50
0
Rods
Cones
−80
−60
−40
−20
0
20
40
60
80
Angular distance from the fovea (degrees)

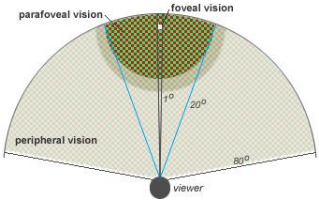
The Macula And Fovea

- The centre-rear of the retina has a small yellow spot known as the *macula*.
- At the centre of the macula is the *fovea*.
- The fovea has a large concentration of cone cells, and no rod cells at all.

High Resolution Vision

- In normal light, the fovea is the part of the eye which yields the highest resolution.
- The fovea occupies about 15° of our visual field (slightly larger than the moon).
- The highest resolution of all is given by the *fovea centralis* which gives occupies about one tenth of this.

The Resolution Of The Visual Field



The picture on the right shows the resolution with we would expect to see the face of the child if we were to stare fixedly at the child's right eye.

Night Vision

- In very low light or at night we see using only our rod cells.
- The rod cells are concentrated away from the centre of our visual field.
- At night we have a “blind spot” at the centre of our visual field.

Neural Connections

- A network of nerves gathers signals from the photo-sensitive cells of the retina and conducts them to the *optic nerve*, which is attached to the sclera at the rear of the eye.
- The optic nerve conveys the information from the retina to the visual processing centres of the *brain*.

The Blind Spot

- There are no photo receptors where the optic nerve reaches the retina.
- This creates a “blind spot” in the visual field of each eye.
- We are usually unaware of our blind spots because information from the other eye is used to fill in the missing part of the visual field.

Finding Your Blind Spot

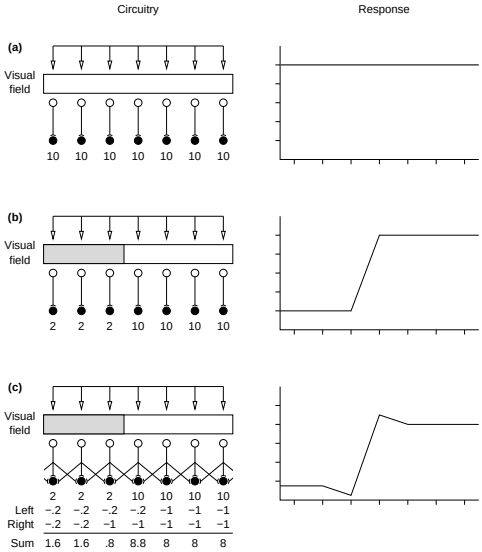
- Draw a cross and a dot about 8cm apart as shown below.
- Close your right eye.
- Look directly at the cross
- Move the page backward and forward until you see the dot disappear.

Retinal Circuitry

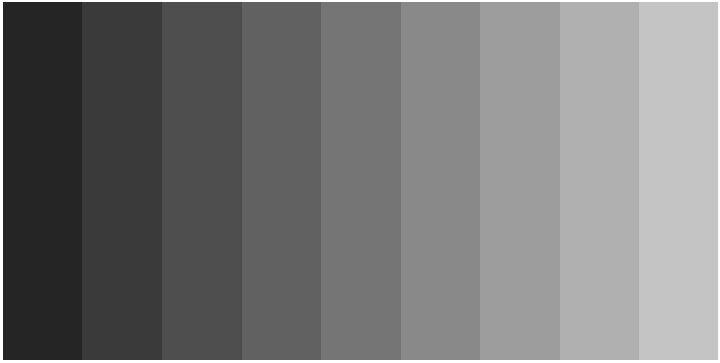
- In the retina, horizontal cells connect photo receptors together.
- These connections mean that some simple image processing can take place in the eye.
- Some of the most important operations are based on *lateral inhibition*.

Lateral Inhibition

- A network exhibits lateral inhibition if a positive outcome in one element of the network, induces a negative outcome in its neighbours.
- Lateral inhibition can be used to produce a simple form of edge enhancement.
- It can also be used to help provide hue and tone discrimination.
- The phenomenon of *Mach Banding* shows the effect of lateral inhibition in the vision system.


Circuitry
Response
(a)
Visual field
10 10 10 10 10 10 10
(b)
Visual field
2 2 2 10 10 10 10
(c)
Visual field
2 2 2 10 10 10 10
Left −.2 −.2 −.2 −.2 −1 −1 −1
Right −.2 −.2 −1 −1 −1 −1 −1
Sum 1.6 1.6 .8 8.8 8 8 8

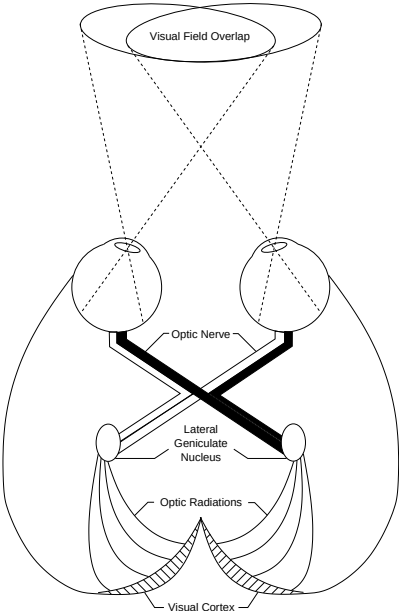
Mach Banding



Neural Processing

- After the visual signal leaves the eye, further processing takes place in stages down the *visual pathway*.
- Many of the steps in the processing of the visual signal are incompletely understood, but some progress has been made in understanding the process.

The Eye-Brain System



Transmission To The Cortex

- The visual signal from the retina is transmitted down the optic nerve.
- There are roughly 1,000,000 nerve fibres in the optic nerve and some 125,000,000 receptors in the retina. The signal is thus not transmitted in a one-fibre per receptor fashion.
- The greatest convergence occurs for the rod cells — the signals from 1000 or more rods may be carried by the same nerve fibre.
- There is evidence that each receptor in the central fovea is connected to two nerve cells.

The Optic Chiasm

- The optic nerves from the two eyes converge and cross at structure call the *optic chiasm*.
- Signals from each eye are mixed at this point. Such combination is clearly necessary for filling in the blind-spot and for comparison leading to the extraction of depth information.

The Lateral Geniculate Nucleus

- The signals a transmitted back through the brain to the *lateral geniculate nucleus*. The LGN acts as a kind of relay station which dispatches the signal to the visual cortex.
- The true function of the LGN is more complex than just acting as a relay, because it also receives a good deal of input from the cortex in addition to the optic nerve.

The Visual Cortex

- The visual cortex contains a number of neural structures which extract basic information from the visual signal.
- There are groups of neurons which are dedicated to detecting lines with particular orientation.
- Other groups take this information and use it to detect shapes.
- The signal is processed at higher and higher levels and eventually passed forward to the higher brain centres.