Vision 1: the retina

Eye anatomy

The eyeball consists of several layers, the outer layer consists of the cornea and sclera and it is responsible for protection. The middle layer contains blood vessels and is important for nutrition, and finally the inner layer is the retina. The retina contains the photoreceptors and sensory neurons etc. that convey visual information up to the brain. Our ability to see most detail and colour is restricted to a small area of the retina called the macula. One can be profoundly blind with minor damage to the macula, but appear to see fine with lots of damage around but not including the macula.

How do we see?

The limits to our visual acuity come from neural factors and optical factors. The optical factors include:

- pupil size
- clarity of the layers in front of the retina
- refractive errors e.g. myopia - short sighted, astigmatism etc.

The neural retina

Light must go through several layers before it reaches the photoreceptors. This is because the layer below the photoreceptors absorbs stray light, and provides them with nutrition. The types of photoreceptors are:

- Rods are responsible for night vision. They are very sensitive, only consist of one type, are very numerous in the retina, but they're absent from the fovea.
- Cones are for day vision, they are less sensitive, there are three types (RGB), and there are far fewer cones than rods in the eye but far more cones in the fovea.

The macula (central vision) has the highest density of cones which means during the day we have great vision. There are no rods in the central part of the macula, they are maximal off to the side by about 8 degrees. This means that at night our vision is poor because at our macula we have no rods.

Photoreceptor function

Photoreceptors contain proteins called photo pigments in the membrane that are activated by light - rhodopsin in rods, one of three different cone-opsins in cones. Opsins bind to vitamin A (retinal) which picks up the light and undergoes a structural change (11-cis retinal to all trans - it straightens out).

The photoreceptor ultimately hyper polarises when light falls on it. This is opposite to most sensory neurons. Neurons in the retina don't use action potentials as the main

communication type (only ganglion cells use action potentials because they output to brain). The response to light is a graded change in membrane potential, this affects the tonic release of glutamate by increasing or decreasing it. The neurotransmitter release is never stopped, only modulated by the light (different mechanism whereby membrane potential not action potential affects neurotransmitter release).

In the dark - cGMP gates a sodium channel (holds it open) causing continuous influx of sodium ions. This causes sustained depolarisation of the cell.

In the light - cGMP breaks down to GMP and the sodium channels are no longer held open. The flow of sodium ions ceases and the cell is hyperpolarised. This is phototransduction,

In summary, the basic steps are:

- light activates rhodopsin by causing a conformational change in retinal
- activated rhodopsin activates transducin protein which itself activates phosphodiesterase.
- Phosphodiesterase breaks down cGMP causing closure of sodium channels and ultimately hyper polarisation.

Retinal circuitry

Once the photoreceptor has been activated the signal goes through bipolar cells which communicate to ganglion cells. There are two types of cells that fine tune the pathway - horizontal cells (outer retina) and amacrine cells (inner retina).

Bipolar cells

There are 10 types of bipolar cell: 9 cone-type and 1 rod type. They receive info from photoreceptors and output to ganglion cells. There are so many types because they have to decode various information and send it to the right places. Bipolar cells are important for spatial information and colour.

Ganglion cells

Ganglion cells are the ultimate output neurons of the retina. There are many types of ganglion cells as well but the main 4 are ON, OFF, M, P. They all communicate different information to the brain. The ganglion cells do fire APs because they have to communicate with the back of the brain, they also use glutamate. Ganglion cells respond to light by either increasing or decreasing their firing rate. The receptive field of a ganglion cell is the area over which the retina will be stimulated with light. Not necessarily activated, could be deactivated depending on the position. This phenomenon is called an antagonistic centre vs. surround receptive field. This is important for the detection of edges.

It turns out that ganglion cells also have a temporal resolution with respect to their receptive fields to. Overall the 20 distinct types of ganglion cells = 20 types of information that come from them e.g. edges, solid. The retina deconstructs the image before sending it to the brain so it can be more easily understood. The selective nature of ganglion cells is partially down to lateral inhibition.

Lateral inhibition

Horizontal cells - sit in the outer retina close to the photoreceptors. They have long processes that project across the retina horizontally. They receive input from photoreceptors then provide output onto photoreceptors to inhibit them with GABA. Horizontal cells determine the unique properties of the ganglion cells.

Amacrine cells - these are many types of axonless cells that receive input from bipolar cells and send it back to bipolar cells and ganglion cells. Amacrine cells use GABA or glycine to modify the retinal pathway in the inner retina. One example of their role is in communicating information about motion.

Vision 2: CNS processing

Ganglion cells pathway to CNS

The response of ganglion cells is determined largely by where you shine the light in the receptive fields (central acts in opposition to surround). Ganglion cells that turn on in response to light on the central part of the receptive field are ON cells and OFF cells are those that are inhibited by light in the central part of the receptive field. Another functional category are M and P:

- M or parasol ganglion cells are large cells with large receptive fields. Because of this they are not good for visual acuity but great for motion detection, flicker, and/or gross features etc. Anything coming across the visual field quickly will be detected by these cells.

- The vast majority of ganglion cells are P or midget ganglion cells which are smaller and more numerous. They fire variably in response to different wavelengths to give visual acuity and colour vision.

The above two types may also be ON or OFF. The ganglion cells output mainly to the lateral geniculate nucleus (in the thalamus) via the optic nerve. Some ganglion cells go elsewhere but the LGN is the key output.

The visual pathway

Retina -> optic nerve -> LGN -> optic radiations (various tracts) -> visual cortex (also called the striate cortex or V1)