Visual System I and II

Development of the eye (Langman's Pg 394, Fig 17.1 – Neuroscience expl. Book pp 44)
The optic grooves develop from the side of the forebrain at about the 4 week period of embryological development. The neural tube has closed by now, so these two outgrowths are referred to as the optic vesicles. These vesicles come into close contact with the surface ectoderm – inducing the ectodermal cells to proliferate. This thickening of the surface ectoderm is called the lens placode. Soon after, the optic vesicle invaginates forming a double walled structure, the optic cup, – initially having an intraretinal space but later this disappears. The optic stalk – future optic nerve – is the connection between the optic vesicle and the optic cup. The lens placode subsequently invaginates to form a vesicle of its own (pinching off the ectoderm) – known as the lens vesicle.

Layers of eye & lens (Nolte 5th Ed pp 411, Fig 17.2)
The outermost tissue layer is continuous with the dura mater of the brain – it is tough, white layer – mainly collagenous tissue. This layer largely forms the sclera – "the white coat of the eye" – and this continues with the optic nerve as a white sheath. The limbus is the circular transition from where the transparent cornea begins. It covers the anterior portion of the sclera and is the entry point for light into the eye. The cornea is important for focussing and changing the refractive index – and is a avascular structure – although heavily innervated by ophthalmic branch of the trigeminal (V) nerve.

The middle layer is called the uvea (choroid). This is a heavily pigmented, vascular and innervated layer. The optic nerve doesn't travel here, although many capillaries and smaller nerves reside in this layer. The pigment is melanin – and is responsible for absorbing stray light. Choroidal capillaries supply retinal photoreceptors. The uvea continues anteriorly as the ciliary body, containing the ciliary muscle, and the main part of the iris. The ciliary muscle controls the shape of the lens, and the iris regulates the size of the pupil via the pupillary sphincter (circularly arranged smooth muscle) and dilator (radially arranged smooth muscle).

The inner most layer is two layers thick. It derives from the embryological optic cup. The retina closely lines the choroid. The outer layer, closest to the choroid, is the retinal pigmented epithelium (important for absorption of excess light, and phagocytosis of 'garbage') and the inner layer is the neural retina. The retina is loosely attached to the choroid; therefore significant disturbance will cause retinal detachment. The retina ends anteriorly at the ora serrata but the double layered structure continues into the ciliary pigmented epithelium – lining the ciliary body.

The lens is attached to the ciliary body by zonular fibres (suspensory ligament of the lens). These fibres are attached to the folds of the ciliary body (ciliary processes). The ciliary muscle (innervated by oculomotor nerve CN III) – is attached to the sclerocorneal junction. When this muscle contracts – it shortens the ciliary body, in turn shortening the suspensory ligament – relieving the tension of the lens – therefore thickening the lens. This is important for accommodation (focusing on near objects).

Shape of eye maintained by intraocular pressure (Nolte 5th Ed pp 411)
Much like a basketball which maintains its shape due to the intra-ball pressure – the eye is able to maintain a spherical shape due to the pressure generated within – due to the fluid compartments. This is similar to the ventricular circulation of the brain. The ciliary epithelium produces the CSF-like fluid called aqueous humour. This is produced into the posterior chamber – between the iris and lens. Due to the continuous production – the aqueous humour travels through the pupil and into the anterior chamber – between the cornea and lens – through the granulations at the iridocorneal angle to enter the canal of Schlemm. This canal drains into the venous circulation.

The vitreous space is filled with gelatinous material called vitreous humour. The granulations offer some resistance to drainage of the aqueous humour – this causes some pressure – which is transmitted throughout the posterior compartment (vitreous space) therefore enabling it to maintain its shape. Similar to the clinical condition of hydrocephalus – glaucoma results due to accumulation of aqueous humour either due to: too much production or too little reabsorption. Ultimately, increase in intraocular pressure results – causing retinal damage.

Cornea and lens focus images on retina (Notes – Refer to diagram from lecture)
If you haven't taken down the diagram – then you can get it off me – it makes the whole matter so trivial. Note that: cornea and lens function to focus image on retina.

Emmetropia: normal vision, image focused on retina
Hyperopia: image focussed behind retina (long sighted)
Myopia: image focussed in front of retina (short sighted)

Cell types of retina (Nolte 5th Ed pp 414, Fig 17-4, 17-5, 17-6)
<u>General pathway</u>
The retina is neatly arranged into five layers, three of which are occupied by cell bodies of cells, and two layers occupied by synapses. Fig 17-4 brilliantly highlights the simplicity of the connections. The photoreceptor cells are stimulated by light, information is projected to the horizontal and bipolar cells. The horizontal cells project laterally to other receptors, horizontal cells and bipolar cells. The bipolar cells directly convey the information to the ganglion cells & amacrine cells, whose axons become the optic nerve. Processes of the amacrine cells project laterally, and connect to other amacrine cells, ganglion, and bipolar cells.

<u>Layers of retina</u>
Retinal pigmented epithelium (one side faces the highly vascular choroid; the other side has numerous processes facing the receptor cells). Play a metabolic role with the receptors, and absorption of light which has passed through the retina.

The **rods and cones** are photoreceptors. Each has an outer and an inner segment. The outer segment (site of visual transduction) of a rod is cylindrical, whereas of a cone is tapered. Disks fill the outer segment of each receptor. Rods have completely intracellular disks and cones have disks continuous with the extracellular space. The main protein constituent of the outer segments of rods is rhodopsin, and of cones is – cone pigment. The inner segment is composed of the cellular constituents of these photoreceptors – largely containing mitochondria. Rods are to do with low acuity, monochromatic vision, dim light (scotopic vision), cones are to do with high acuity, colour vision, require more light (photopic vision).

Outer limiting membrane: Formed by the collection of intercellular junctions between Muller cells, which span almost the entire retina terminating in junctions at this limiting membrane. Muller cells are specialised glial cells.

Outer nuclear layer: consists of cell bodies of rods and cones

Outer plexiform layer: This is a layer of synapses. The receptor cells project and synapse with horizontal and bipolar cells. It also contains lateral spread of processes of horizontal cells.

Inner nuclear layer: Contains the cell bodies of all the retinal interneurons and those of Muller cells.

Inner plexiform layer: This is a relatively thick layer consisting of synapses between bipolar cells → ganglion cells and amacrine cells. It also contains the lateral processes of the amacrine cells. More than 30 different types of amacrine cells have been described → very complex layer.

Ganglion cell layer: Contains the cell bodies of the ganglion cells, the dendrites of which extend into the inner plexiform layer. The ganglionic axons leave as the optic nerve. This is a relatively thin layer compared to other nuclear layers, reflecting the fact that there are millions of more photoreceptor cells when compared to ganglion cells. This implies convergence of retinal processing, but this is not evenly spread throughout the retina. Level of convergence is proportional to degree of sensitivity.

Nerve fibre layer: This is a layer of axons of ganglionic cells, converging toward the optic disk (posteromedial to the midline of eye). The central retinal artery (branch of ophthalmic artery) enters the eye at the optic disk (following the optic nerve pathway). Dual blood supply of eye → choroidal capillaries + central retinal artery.

Inner limiting membrane: This membrane separates the inner vitreous space and the proximal portion of Muller cells.

Note: You should know the above like how an Indian knows his curry, which is "damn well"!

Parts of retina (Nolte 5th Ed pp 419)
The optic disk is a retinal landmark where the ganglionic axons converge to form the optic nerve. This nerve penetrates the sclera (lamina cribosa) and exits to enter the cranium. This area of the retina contains NO photoreceptors, interneurons and ganglion cells – which implies that any object which falls on this area is simply not processed. This is referred to as the blind spot. An increase in intracranial pressure causes oedema in the nerve fibre layer – known as papilledema. The macula lutea is a yellowish area near the optic disk. In the centre of this is a depression of the retina called the fovea. This is particularly rich in cones, providing high spatial acuity and colour vision. Note that the light hits much closer to the photoreceptors compared to other areas of the retina. The fovea is directly in line with the visual axis. To maintain the highest acuity, specialised bipolar cells → midget bipolar cells and ganglion cells → midget ganglion cells exist in the foveal region.

Now you know that the fovea is used for high acuity colour vision in bright light, where extra foveal regions are used for low light.

<u>**For interest**</u>

1) Why isn't there a blind spot in our visual field → this is because the brain "fills in" the space with a conjured up image representative of the true object. Thus, functioning like how a computer animates "non-real-like" objects, representative of the true object.
2) Why isn't the whole retina as specialised as the fovea → thus avoiding the need for convergence by the lens → therefore avoiding hyperopia and myopia and achieving images with the best acuity. This is because the amount of cortex required to do this will exceed 100 times the cortex available for the entire brain.

Photo transduction (Nolte 5th Ed pp 422)
The photoreceptors contain rhodopsin and cone pigments. These pigments absorb light. The process of photo-transduction is explained below:

- Receptor protein opsin binds vitamin A derivative 11-cis-retinal (Now the photopigments can absorb light)
- Light hits the photopigments → 11-cis-retinal → isomerised to all-trans-retinal → dissociates from opsin
- Opsin changes in shape and activates nearby G proteins (transducin) → G proteins therefore activate phosphodiesterase → and this functions to hydrolyse cGMP
- Note that the membranes of rods and cones have cGMP – gated cation channels. In the dark, the levels of cGMP is high – gates are always open. When light hits, levels of cGMP are low (due to hydrolysis), therefore $Na+$ gated channels close – membrane hyperpolarises → neurotransmitter release declines (glutamate) → therefore activation of bipolar cells and ganglion cells is declined.

<u>**For interest**</u>
Notice that the photo-transduction process works in reverse. Light induces decreased activation of bipolar and ganglion cells, and darkness induces greater activation. Isnt this an inefficient system? Well, think about the sleep/wake pattern. As time goes on, we get less and less sleep (darkness) – so the above process may evolve to become light receptors, and not "darkness receptors".

<u>Classes of rods/cones:</u> 1 class of rods, 3 types of cones: red (X chromosome), green (X chromosome), blue (chromosome 7).

Ganglion cells (Nolte 5th Ed pp 426)
A cell can be characterised by its receptive field. That is – the area in which changing conditions can influence a cell's activity. In this case, the area in which change in illumination affects the ganglionic cell activity. Research shows that ganglion cells have as receptive field composed of an ON centre and an OFF centre. For example: illumination of the central ON centre will stimulate the ganglion cells in this area, and will inhibit the ganglion cells in the OFF centre. You may think – it's the illumination that is the major factor – but in fact the level of illumination is not significant at all. It's the level of contrast between the two centres that is of paramount importance. For example: illumination of the central ON centre – means there is now a significant contrast between the ON centre and OFF centre – therefore triggering the stimulation of the cells with varying degrees.

Visual pathway (Nolte 5th Ed pp 431, Fig 17-24, 17-25)
"Half of the visual field of each eye is mapped systematically in the contralateral cerebral hemisphere" (Nolte J., 2002). Axons of the ganglion cells travel together as the optic nerve. The two optic nerves converge to form the optic chiasm (anterior to the infundibular stalk), undergo partial decussation to become two independent optic tracts. These fibres are myelinated and have oligodendrocytes interspersed among them. The partial decussation of optic nerve fibres refers to:

- Fibres from nasal retina crossing (contralateral)
- Fibres from temporal retina not crossing (ipsilateral)

Fibres from the optic tract then terminate on the lateral geniculate nucleus → from here travelling through the internal capsule and corona radiata to the primary visual cortex near the calcarine sulcus (extension of the paraoccipital sulcus). Some fibres also project to the midbrain (superior colliculus) and hypothalamus.

Lateral geniculate nucleus (Nolte 5th Ed pp 432, Fig 17-26)
The optic tract terminates at the lateral geniculate nucleus (LGN) which is formed by 6 layers. Layers 1, 4, & 6 receive inputs from the contralateral eye, whereas layers 2,3, & 5 receive inputs from the ipsilateral eye.

Layers 3-6 have small neurons, which receive their inputs from the most common type of ganglion cells, sensitive to colour and form. These layers are referred to as the parvocellular layers, and subdivision referred to as the parvocellular system. The magnocellular layers are 1 & 2 (known as magnocellular system) – contain larger neurons and receive their input from a separate class of ganglion cells that is sensitive to movement and contrast. From here, the fibres travel through the internal capsule, travelling around the lateral ventricle, terminating at the primary visual cortex (geniculocalcarine tract = optic radiation). Some fibres pass around the inferior and posterior horns of the ventricle (Meyer's loop) and then radiate to the primary visual cortex. These fibres represent superior visual quadrants (i.e.: from inferior retinal quadrants). Retinotopic arrangement refers to the fact that fibres representing superior quadrants project most inferiorly and vice versa. Thus inferior visual fields are mapped superior to the calcarine fissure, whilst superior visual fields are mapped inferior to the calcarine fissure. The macula is represented most posteriorly – and macular fibres occupy a middle area (while projecting).

Superior colliculus – Midbrain (Nolte 5th Ed pp 437)
The function of the superior colliculus (SC) is poorly understood – believed to be involved in head movements in response to visual stimuli. The SC receives retinal and cortical input. (Retinal input) Some fibres from the optic tract bypass the LGN – cross the MGN in a bundle called brachium of the SC to terminate in the SC and in the pretectal area, and other accessory optic nuclei. The cortical input arises from area 17 – to project to the SC following the retinotopic arrangement.

The hypothalamic projection involves some optic tract fibres projecting to the suprachiasmatic nucleus (located superior to the optic chiasm). This nucleus is the "master clock" for timing of the circadian rhythm.

Organisation of the visual cortex (Nolte 5th Ed pp 441)
The visual cortex has a modular assembly, with each module made up of smaller columns. Neurons within the same columns have similar physiological properties. The columns making up one module – analyse the visual information coming from a small portion of the visual field. Modules are larger as you move more peripherally from the fovea. Thus the number of modules making up the foveal part is higher than the number of modules making up the peripheral part of the retina.

Visual defects named according to visual field defects, not retinal defects (Notes)
Refer to notes provided in lecture

Reflex circuits (Nolte 5th Ed pp 444 Fig 17-38, Fig 17-40)
<u>Pupillary light reflex (Direct vs. Consensual)</u>
Here is the basis of the pupillary light reflex:

- Light is illuminated onto one eye – eventually will cause both pupils to constrict → how?
    - Impulse travels via the optic nerve → optic chiasm → optic tract → some fibres terminate at the LGN → other fibres bypass this to terminate at the pretectal area (via the brachium of the SC).
    - Post-synaptic pre-tectal neurons project bilaterally to both Edinger-Westphal nuclei on both sides of the brain (via posterior commissure and periaqueductal grey ventral to the aqueduct).
    - Post-synaptic axons of cells of Edinger-Westphal nucleus travel in CN III (oculomotor nerve) as pre-ganglionic parasympathetic fibres to the ciliary ganglion → post ganglionic fibres synapse on the smooth muscle cells of the pupillary sphincter – constriction of both pupils (acting via suspensory ligaments).
    - Swinging flash light test (refer to: Pg 445 of Nolte 5th Ed)

<u>Accommodation (Near reflex)</u>
Here is the basis of the accommodation reflex:

- Three things happen:
    - 1) convergence of two eyes so image falls on foveae
    - 2) contraction of ciliary muscle, thickening of lens
    - 3) pupillary constriction → improves optical performance
- How:
    - Optic tract → axons project to LGN → project to visual cortex → visual association cortex → superior colliculus → oculomotor nucleus (stimulating medial rectus motor neurons) + E-D nucleus