Vision; Introductory Lecture 2017

This course is about vision; how you see and why you see.

Catch a Ball

Vision starts at the eye; An inverted image is formed at the back of the eye by the cornea and lens (Thank you Kepler!). The image is transferred into electrical signals by light sensitive cells. The image is connected by two successive cell layers of the retina into a signal than is carried by optic nerve fibres to the brain. In humans, the most important target of the optic nerve is a nucleus in the thalamus, the ***Lateral Geniculate Nucleus***. A formidable name, it just means a little knee-shaped structure.

From the lateral geniculate, the fibres project to a region of the cerebral cortex, called ***the striate cortex,*** in the back part of the brain. This region of cortex is called striate, or striped, because in this area of cortex there is a white stripe parallel to the surface, and about half way down from the surface to the white matter (Thank you, Francesco Gennari!).

The visual image is processed further by cortico-cortical relays to adjacent secondary cortical areas; shapes processed primarily in the temporal lobe (Thank you, Charley Gross), motion, in the parieta1 lobe (Thank you, Semir Zeki!)

From these secondary visual areas, there are connections via midbrain, cerebellum and basal ganglia to motor areas, some controlling eye movements, some to the motor cortex, thence by way of descending tracts in the spinal cord to motor neurons controlling the hand and fingers (thank you, among others, Roger Lemon!)..

I hope that this course will teach you a great deal of what is known about these topics. My own approach to helping you understand them is historical. Often a very simple experiment or clinical observation is the best way to learn what is known about how the visual system works.

The first problem to understand is the nature of white light and *how* the image is formed at the back of the eye by cornea and lens.

SLIDE 1 Human eye after Walls

A glass surface bends light which allows us to make lenses and prisms. White light consists of rays of many wavelengths, hence many colours. Because rays of differing wave-length are bent more or less sharply by a glass surface, a prism can project a coloured spectrum onto a surface. It was with prisms, that we first began to understand the composition of white light. Many people assume that the first demonstration of the compound nature of white light was by Isaac Newton but lenses and prisms were in wide use before Newton.

SLIDE 2 Boyle's prism

SLIDE 3 Newton ; portrait with colour wheel

Newton's contribution was to show that the rays retained their characteristic colours even when further refracted by a lens or prism and that a second prism could re-combine the separate rays to make white light.

With Newton's help, we began to understand the physics of light; the constituents of white light, and how colours can be mixed. There is a parallel tradition of self-study; using human observers to further understand the nature of vision, going back to the German poet Goethe, and the Czech physiologist Purkinje. One obvious problem is colour. We can see and distinguish hundreds of colours in a well-lit scene. Do we have a special receptor for each?

SLIDE 4 Thomas Young 1802 Portrait and quote;

"It becomes necessary to suppose the number limited, for instance to three principal colours…."

Chromatic Aberration

Colour enlivens our world, but it poses problems for clear vision, since short-wavelength light is imaged at a different plane to long wave length light. Chromatic aberration limits the clarity with which we can see small objects. In the early 19th century optical engineers began to solve the problems posed, by chromatic aberration by combining lenses that could minimise it. Microscope lenses became available that allowed far more detailed observation of biological structures than had been possible earlier.

SLIDE 5 Schultze Schwalbe 1870 and modern, stained monkey retina to show cones and rods.

Anatomy made major advances with the new microscopes, and there were parallel developments, equally important for preparing tissue; ways to preserve and stain it.

In order to try to see the true shape of nerve cells it was necessary to harden the tissue and then slowly dissect out individual cells; a painstaking and distorting procedure. In 1870s Camillo Golgi invented a silver based stain that was to revolutionize neuroanatomy. In 1892 The Spanish anatomist Santiago Ramon y Cajal used the Golgi method to stain, study and describe all of the cells in the vertebrate retina in beautiful detail

SLIDE 6 Cajal 1892 Connections and cell types in the vertebrate retina.

Cajal provided us with a superb description of the cell types of the retina. One hundred years later, the physiologists began to catch up.

The final layer of cells in the retina is the ***ganglion cell layer.***
In all vertebrates, a prominent nerve, the ganglion cells give rise to the ***optic nerve*** which emerges from the back of the eye, and heads towards the brain.

We pause here, with two inter-related questions;

1) Where does the nerve go in the brain?

2) How does the nerve work?

Let us first answer the question of the target of the optic nerve. The optic nerve is composed of axons arising from the ganglion cell layer of the retina. There are several targets of the optic nerve. but the most prominent, and most important for human vision is to the ***Lateral Geniculate nucleus.***
On its way to the geniculate, the nerve descends along the base of the brain to a prominent X –shaped structure the ***Optic Chiasm***. Until the 1880s there was no universal agreement on what happens at the chiasm. Some claimed complete crossing, some partial crossing, and some uncrossed.

One observation that began to suggest how it works was by William Henry Wollaston.

SLIDE 7 Wollaston and quote

The true situation had actually been suggested by Newton (and largely ignored). Wollaston, and finally Von Gudden some forty years later (before he came to an untimely death in company with King Ludwig of Bavaria).

SLIDE 8 Circle of Willis and the optic chiasm seen at the base of the brain

IMPORTANT POINT; If a person has a lesion behind the chiasm in the geniculate or visual cortex, they become *hemi-an-opic* Half not-seeing. They see the visual field only on the side of the lesion. Why??

The human and monkey geniculate is prominently laminated, with six obvious cell layers separated by fibres. Each layer is precisely aligned with the visual field. In the1920s Miecyslav Minkowski studied the brain of a woman who had lost one eye forty years previous to her death He found layers 1, 4 and 6 atrophied on one side 2,3, and 5 on the other.

SLIDE 9 Trans-neuronal atrophy in the monkey geniculate

Localisation of the visual cortex

In 1850 there was no evidence for localization in the cerebral cortex. By 1900 cortical localization was an established fact.

Two discoveries opened the question of localization; One was Broca's discovery of a language speech area in the frontal lobe in the 1860s, the other was Gustav Fritsch and Edward Hitzig of a specialized region of cortex which, when stimulated electrically, produces movement on the opposite side of the body. The search was on for a visual area. For a reason we can now understand, David Ferrier mis-localized the visual area in the parietal lobe. It was Herman Munk who first showed in 1882 that monkeys, became hemianopic after removal of one **occipital lobe.**

SLIDE 10 Hermann Munk and the occipital lobe

Ten years later, the Swedish neurologist, Salomon Henschen, identified the primary visual cortex in the occipital lobe

SLIDE 11 Henschen and Hemianopische Falle

By now it should be clear that there is a spatially organized map of the visual fields projected onto the striate cortex; nearby points in the visual field are represented at nearby points in the visual cortex. How is the map organized? Henschen had two directions right; one dimension wrong. He correctly placed the left visual field representation in the right hemisphere, and the upper visual field on the lower bank of the **calcarine fissure.** But he had the central-peripheral directions wrong; placing the foveal representation at the anterior end of the calcarine fissure.

A young Japanese physician, Tatsuji Inouye, studied casualties of the Russo-Japanese war 1904-1905

SLIDE 12 Inouye and the Russo-Japanese war

SLIDE 13 Inouye's map and a plot of muzzle velocities of the Russian rifles.

HOW DO NERVES WORK?

The image in the eye is coded in electrical signals and carried over a series of nerve fibres from the retina, followed by the geniculate to the cortex.

The important distinction between local and propagated axonal conduction.

The receptors in the human eye are rods and cones. They are continuously active. Unlike receptors in the skin, rods and cones increase the voltage across their membrane in response to light.

Initial sensory activation is local. Axonal conduction is fundamentally different; it is ***propagated***. Axons must conduct information over great distances. Retinal ganglion cells transmit a processed image formed by the receptors to the brain. The message is filtered and ordered by the cells in the inner nuclear layer, which lies between the receptors and the ganglion cells. Rods and cones and the cells of the inner nuclear layer act by local conduction. Thus, the retina tends to be of a constant thickness in all vertebrates. Although the size of the eye in vertebrates varies greatly the retina in all vertebrate eyes is about the same thickness. The elephant retina is about the same thickness as that of a rat.

The human retina is provided with a complete set of rods and cones. In the earliest stage the two systems are in parallel. In the case of rods v. cones, when one set is working, the other is not.

Nerves **Work Electrically**

Slide 14. Electric Eel and Galvani

Electric phenomena had been known for centuries, but until the 19th century electricity itself was poorly understood. Early pioneers thought of electricity as a kind of fluid that could be generated and stored. In the late 19th century, Galvani argued that animal electricity must be involved in nerve conduction.

How fast do nerves conduct?

The frog spine and attached sciatic nerve can conduct electricity for some time after death, and activate the target muscle. The preparation is useful for answering fundamental questions

Slide 15, Helmholtz and speed of conduction

By the middle of the 19th century, it had become certain that axons must act electrically, but there was little understanding about how they do so. A first question is that of speed. How fast do they conduct? The question seemed unanswerable. The assumption was that the speed would resemble that of conduction in a copper wire. Helmhotz set op the sciatic nerve-gatscnemius muscle and stimulated it at two different points. Nerves conduct at a finite and measurable speed.

Slide 16. Sciatic nerve

Helmholtz recorded the action of the muscle after maximum stimulation of the sciatic nerves. All of the axons would have been stimulated But the diameter of the axons in a peripheral nerves is not uniform. Does that matter?

Slide 17. Hartline's crab

One of the great contributors to neuroscience is finding a preparation that can reveal fundamental principles of sensory physiology. One of the earliest and greatest was recording from single ommatidia, of the compound eye of the horseshoe crab *limulus.*

Slide 18. Hodgkin and Huxley

Since Helmholtz, it was clear that conduction along an axon must be mediated by ions, As early as 1890s Bernstein had shown that there is an unequal distribution of sodium ions across nerve cell membranes. The action potential was thought to be a simple breakdown of the voltage across the axonal membrane; each patch of membrane causing the next patch to depolarize, similar to the action of a firecracker fuse. In 1937 JZ Young found that squids have a giant axon; so big that you can put an electrode inside it to record and stimulate. Rather than a simple depolarization, the action potential works by a successive pair of permeability changes; first to sodium, then to potassium ions.

Slide 19. Elliot and synapse

What happens when an axon contacts a muscle, or the next nerve in a neural circuit? Elliot found that autonomic muscles seem to respond identically to stimulation of the attached nerve and local application of adrenaline. He made the remarkable suggestion that nerves nay act by liberating a small amount of a transmitter substance.

Slide 20. Synapse Bain

Elliot's insight remained unproven until the 1920s. Proof came from study of an isolated frog vagus nerve- heart preparation. Stimulation of the vagus nerve cause a frog heart to beat more weakly and slowly. Otto Löwi showed that if you collected the fluid from a stimulated heart, and injected into the same or another heart it would have the same effect. Something was liberated.

Slide 21. Fish and snake

If you list all, the stages from activation of a sensory ending through to transmission of the signal, and then transmitter release followed by activation of the next nerve in the pathway. Some animal or plant knows physiology as well as you do, and uses it for self-defence or predation.