Slide 1) **Neuroscience C 3045; Eye and Brain**

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Comparative Anatomy of the Eye

Let's start with a retina, and then go back to structure of the whole eye

Slide 2) King Snake

A three layered all-cone retina. Let's think how it might be modified in different animals to suit different life styles.

The general problem of vision; what sorts of things can you do with your eyes? The eye, like other excellent optical devices forms an image of the world in front of it. Visual direction is probably innate. In addition there is vision for:

<u>Fine detail</u>: Detection of a small object against a background (<u>visual acuity</u>). Clinical measures 20/20 [6/6] you see @ 20 feet what a normal eye sees at 20 feet. Acuity falls off in peripheral retina.

We can relate acuity to cone density

<u>Sensitivity</u>: How much light do you need to see? Each rod can be activated by a single photon. Cones are less sensitive, they typically carry colour information. Many animals have only a single kind of receptor ; either rods or cones

King snake cones. Typical of a diurnal animal Probably near-blind in the dark, but see heat detectors in many snakes. Look for rod-based retina.

Would you like to be active both in daylight and at night? The mixed retina.

<u>Visual Depth and Distance Perception</u>: How far away is an object? Which of two objects is closer?

Monocular Mechanisms (e.g. Motion parallax; relative angular movement of 2 objects at different distances).

Binocular Stereopsis Fusing of 2 slightly disparate images to form a depth cue Prominent in animals with binocular overlap

Visual expansion; What is the vision of the ground that a pilot has as he lands an airplane?

Differentiate those visual functions that can be solved in the retina, and those that require further processing b the brain

Colour Vision: Identifying, naming, discriminating colours. How is colour processed in the eye and brain?

Start with receptors
For colour vision to be possible, there must be at least two different pigments in the cone.
Imagine a set of different pigments; their output blended by cells in the inner nuclear layer

Form vision: Recognition of your friend's car in front of his house. Recognition of your friend's face.

Imagine an image formed by the cornea and lens, falling on an array of cones Interpretation of that image must be done further by the eye and brain Where?

Movement Detection: Consider the image moving across the array of cones

Is an object stationary or moving? Distinguishing self-movement from movement of something in our field of view.
Visual guidance of your own movement.
Fingers and limbs (grasping an object in front of you; catching a ball))
Whole body; walking along a crowded street: climbing a tree or the north fact of the Matterhorn.

Why have eye moements? Importance of the fovea.

Eye and head movements (In humans; saccadic, pursuit; vergence).

There are structural limits on how many receptors and ganglion cells ca be crammed into the eye. A way around this would be to make an extremely acuitous region, and then have an elaborate mechanism, for pointing the at that region

There is a world in front and behind you. To see it all, we must move our eyes or head
Consider the rabbit and the owl

Accommodation and development of the eye

The lens allows the plane of focus to change; The length of the eye matters. How big is a baby's eye? How big is your eye?

The constancies: Why does brightness remain constant over a broad range of illumination intensities? Lump of coal in sunlight.

Processing beyond the receptor layer

When we consider the anatomy and physiology of the visual pathways, remember that it is these phenomena of vision that direct and focus research. How do the eye and brain do it?

Discuss the classical light-microscopic view of the structure of the vertebrate eye with some general principles that apply to all vertebrates and examples of specialised structures that have evolved in one or another form.

Similarity. To a great degree, all vertebrate eyes are similar. They share an almost identical imaging system (modified in special environments, such as under water).
Compare with compound eye.
Basic Cellular Plan The basic structural elements of the retina are similar in all vertebrates.

Three nuclear layers with five or six cell-types involved in visual transduction and coding

Two synaptic (plexiform) layers

Evolution; Darwin's difficulty

"….if numerous gradations from a perfect and complex eye to one very imperfect and simple, each grade being useful to its possessor can be show to exist…then the difficulty… can hardly be considered real" See article by Lamb et.al. in reference list.

Slide 3) Normal Human Eye; After Gordon Walls

3 "Tunics" of eye
A: Sclera
B: Choroid and iris muscles
C: Retina (and pigment epithelium)
Note also focusing apparatus; cornea and lens and the optic nerve

Differences. Where vertebrate eyes differ it is often related to the light environment in which the animal lives.
Range of Light Intensity. Range of Physical Intensity approaches 10^{12}. No sense organ could work effectively over such a range (10^3/second action potentials).
How to Code? Scale compression (Weber's law). We are sensitive to relative, not absolute light levels.
How to deal with great range in light intensities

- Photomechanical Changes
  Physically restrict the amount of light which is allowed to reach receptors
- Parallel set of receptors (rods and cones) with different threshold and different dynamic range
- "Tuning" ganglion cells so that they report differences in light intensities within receptive field (lump of coal in sunlight looks black)

Mechanical Regulation of Light at the Receptor; Pupils; Is the pupil enough?

4) Tiger

What's wrong with the picture?
Association of slits with nocturnal life style (esp. Snakes)
Round vs. slit pupils. Nocturnal retina requires exclusion of light in daylight "basking"

Is the pupil sufficient as a regulator of intensity? 10 to the12th vs 10 to the third

<u>Pigments and stray light</u>. Stray light degrades the image, it is absorbed in cameras and in the eye by pigment layers.

5) Monkey

Low power of monkey retina with optic nerve
Pigment epithelium plays an important role in light and dark adaptation of lower vertebrates.
Processes interdigitate with tips of receptors.

6) (Skip duplicate)

In most animals, there are there are two blood supplies; one via the choroid and pigment epithelium the other on the surface of the retina. But blood vessels on the surface would be in the path of the light. Why don't we see them? Answer? You will.

7) Pigment epithelium (Hedgehog)
Pigment epithelium is a channel for (choroidal) vascular supply for receptors. Bites off growing rod tips.

Other mechanisms for mechanical regulation of light intensity at the receptor.
Pigment migration in lower vertebrate.

The processes of pigment epithelial cells may extend the length of the receptors.
Image 2 hairbrushes (receptors)
Melanin granules are actively migrating:
Migrate outward in light back towards cell body in dark
8) Dark-adapted fish eye; Pigment retracted into cell body

9) Light adapted fish eye: Pigment surrounds each individual receptor
Augmentation of Sensitivity.

Animals that live in dim light-environment sacrifice precision of an image for increased sensitivity "snapshots vs. time exposures"
suppose light goes through receptor layer without ever being absorbed. If it strikes a reflective surface the receptors have a second chance

What would be the consequences of putting a reflecting mirror behind the receptors in the retina?

10) Eye shine Leopard

11) Tapetum Lucidum

(Note Absence of melanin pigment in pigment epithelium)

Why does the retina need protection against light? Toxicity of Excessive Light

Albinos are especially at risk. Four weeks of continuous moderate illumination; albino rat causes degeneration of receptors

12) Normal rat retina

13) Constant light; retinal degeneration

On examining the retina; The ophtalmoscope and retinoscope

Retinal structure and the accuracy of ophthalmic instruments. To a reasonable approximation the retina of all mammals (vertebrates) is of constant thickness.
14) Rat

15)Whale

16) Elephant

17) Raw data; Eye size and refraction The "Small Eye Effect"

Conclude: retinoscope uses a specular reflection from vitreous-retinal surface
Similar factor applies to opthalmoscope

Growth and Plasticity of Eye Size; Emmetropization

The normal newborn human infant eye measures 17 mm. from cornea to retina; the adult eye 24 mm.
The (strange but true) evidence that eye growth is under local visual control.

Different focal planes in the bird eye Emu and Japanese quail

Fundamental Dichotomy of Rods and Cones; How can we help our snake to see in the dark?

Schultze's dichotomy: Differences in receptor types correlated with the life of the animal: "pure rod" and "pure cone" retinas.
Our retina is mixed rod/cone

18)Monkey retina 3 layers
Rod/cone (nuclei). Note Difference in nuclei of rods and cones.

19) Higher power; conical outer segments
Variability in cone density in human (an monkey) retina; rods are relatively constant

20) Peripheral retina

21) 10^0 Out

22) Follow colour of nuclei at the edge of the fovea

23) Central fovea

Other Plans; The Retinal Streak

24) Lindsay Johnson reindeer

Note 1) Pigment distribution

2) Vascular differences

Receptors and Visual Pigments
Wavelength sensitivity of Receptors.
Outer segments of rods and cones contain photopigments.

1) Absorb light 2) Transduce physical signal into an electrical one:
   Wavelength and Absorption
   Rods peak absorption at 500 nm
2) Absorption spectra of pigment in cones. In human and monkey. 3 classes by microspectrophotometry; intracellular recording.

Requirements for Colour Vision

Colour vision requires at least 2 classes of receptor with different wavelength subdivisions. In principle you could do it either with pigments or with filters.

25) Oil droplets

Variability in Receptor Morphology across species Cones and Rods may be thin or fat

26) Frog; Rods and cones
Note massive rod (also "green" rods; double cones)
Now cut parallel to the inner segments.

27) Gecko retina

Synaptic connections of the retina

Slide 28 Structure of the eye; Cajal 1892

elements: receptors contact both horizontal and bipolar cells
bipolar cells contact amacrine and ganglion cells
amacrine cells contact bipolars and ganglion cells
ganglion cells as final common path

There are two synaptic layers in the eye. Outer plexiform layer containing cone pedicles, rod spherules; bipolar and horizontal cell processes
Much more complex inner plexiform layer. Many cell types in the ganglion cell layer.
Laminar structure of inner plexiform layer

29) Ground squirrel

Differences in ganglion cell size within and between animal species

30) Cat retina

Functional differences between ganglion cells of different morphology.
. m and p cells

The conduction pathway within the eye.

The axons of retinal ganglion cell stake a varied course, some sweeping away from the fovea enroute to optic nerve (myelinated only when they reach the disc hence non opaque)
Note Blue Arcs in demonstrations

31) Monkey whole mount

Convergence & Divergence within the Retina

Receptors as "points"
Ganglion cells as transmitters

Great variability in the complexity of inner nuclear layer
Convergence is generally an adaptation for sensitivity

32) Hamster
But many animals (especially birds!) have massive inner nuclear layer: an active filter

33) Tree shrew

Humans and monkeys have highly convergent peripheral retina roughly equal number of receptors/inner nuclear cells/ganglion cells near fovea

34) Monkey fovea

Why is fovea shaped as it is?

35) Owl fovea

36) Chameleon (Anolis) (Also raptors)