

Vision Lectures I and II

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1 The main issues this semester

What does it mean to be conscious?

What am I?

How do you understand me?

One can duck these issues and study simpler systems, such as a duck, or a snail. However, these questions have always driven me in my professional life. I have always wanted to ask questions as bad as this. Yet we all know that all you need is some beer and you can do much good work on these questions.

The question of levels arises.

Which is the best level to really understand these issues? Of course, we all know that no one level is best

The visual system is a good system since multi-level explanations are available. Start at the retina and work inward in two lectures.

1. Retina
2. Lateral geniculate nucleus and projection zones
3. Striate cortex
4. Extrastriate cortex

2 The case of the colorblind painter by Oliver Sacks

A framework for studying principles of brain function.

Define a cognitive deficit that is interesting	Cerebral achromatopsia
Determine the context of the problem	Verry
Suggest what structures	Homologue of V4/blobs/magnocellular
Provide a workable hypothesis for the deficit	Focal lesion
Question findings	Too simplistic

Facts:

Auto accident

No clear damage (no bleeding)

No recollection of accident

Alexia for five days.

“Driving in a fog”

His studio was “..now utterly gray and void of color. His canvases, the abstract color paintings he was known for, were now grayish or black and white. At this point the magnitude of his loss overwhelmed him.”

“What’s the big deal?”

His vision had an “excessive tonal contrast.”

Over time he adapted. When I met him for the first time, he said when I asked him about his loss, that he didn’t think about it any more. “I am completely divorced from color.”

Thus it appears we have elements of a simple loss, of a simple loss of color. Yet the man's entire life had changed because of this.

How can we account for this?

There is a surprisingly large literature on this (1688). Yet this onset of colorblindness was completely dismissed as hysteria 100 years ago.

What is the cause of this? You now need to learn lots.

3 Retina

Overview

- Phototransduction
- Laminar structure
- Rods/cones - role in acuity, differences
- Horizontal bipolars
- Amacrine
- Ganglion output to optic nerve
- Function - log transduction of light
- Wavelength selectivity - spectrum
- Lateral inhibition
- What the retina sees .. the idea of a filter.

*3.1 Phototransduction and information processing in the retina*¹

3.1.1 Structure of the eye

Retina is part of the CNS- derived from neural ectoderm

3.1.1.1 Pigment epithelium

- full of melanin (absorbs light and stops scattering)
- assist with metabolism/contact photoreceptors
- phagocytosis outer segments of photoreceptors
- **LIGHT TRAVELS THROUGH CELLULAR LAYERS PRIOR TO FOVEA**
- Layers are thin unmyelinated fibers and pass light rather well
- Fovea has cell bodies displaced to reduce attenuation of light signal (foveola - clearest vision)
- **optic disk** - where fibers leave the retina- no photoreceptors leading to the blind spot

3.1.2 Photoreceptors - rods (night vision) and cones (color vision)

3.1.2.1.1 Perceptual differences

- **cones** - higher spatial and temporal, color (see how soon), never saturates (painful), many photons, concentrated on fovea/foveola, convergent on bipolar neurons, contributes to high

¹ based on chapter 28 of Kandel Jessel Schwartz

spatial acuity, 55Hz

- **rods** - low spatial, low temporal, integrates light, monochromatic, saturates, heavy amplification, needs fewer photons (single photon), 20 times as many as cones, 12 Hz
- Rods/cones - role in acuity, densities

3.1.2.1.2 do not fire action potentials, unique neuronal property

3.1.2.1.3 structure of a rod/cone -

- four functional parts
- outer segment - outer distal surface
- inner segment - inner proximal
- synaptic terminal
- stalk or cilium that looks like any other neurons

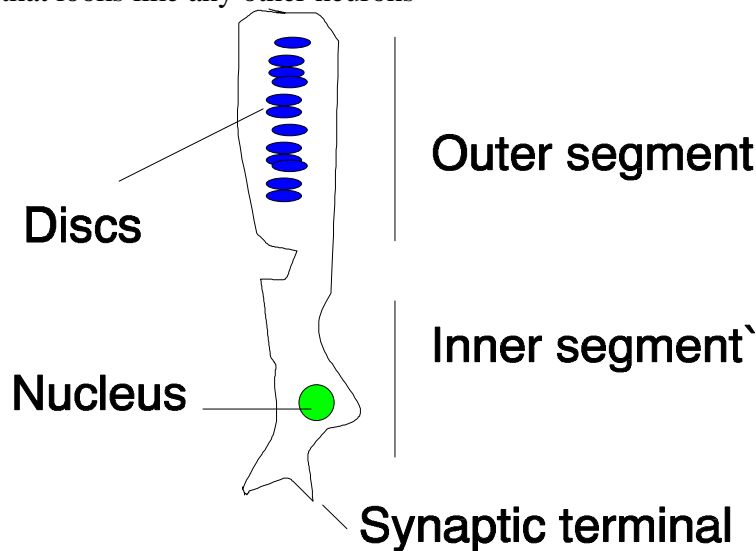


Figure 1 Your basic rod

Ultrastructure

- The disks float in the cell membrane of the outer segment and are full of (10^8) photopigments that are bound to the membrane of the disks via a humongous transmembrane protein.
- The rods have intracellular organelles while the cones' discs remain coextensive with the membrane
- Believe it or not! The pigment molecules are oriented to catch the maximum amount of light and whatever photon gets past one disc gets caught by the one underneath.
- Resynthesis of disc (3/ hour) at the base. At the tip they are trashed by phagocytosis into the pigment epithelium.

3.1.2.2 Phototransduction -

Cascade of long chemical names which you MUST memorize until you past your qualifying exam and then happily forget forever. Except for the word cis-trans , which even I still seem to remember. Here it goes.

The transduction of light

3.1.2.2.1 Detail 1 - Rods

- rods have rhodopsin consisting of *retinal* and *opsin* (in membrane).
- *Retinal* is a form of vitamin A and is hooked to the opsin by a Schiff base linkage (does anyone know what that is?)
- A photon changes the retinal from **11-cis** to **all trans** which means the shape changes.
- That is it for light. From here on it is chemistry.
- Retinal changes its shape and falls off from the opsin.
- Opsin is unhappy and rushes through (< 1 msec) a set of conformational changes to *metarhodopsin II*.
- That Schiff-base linkage within minutes vanishes because meta. II is unstable and it drifts off into the intracellular space and turns back to all-trans retinal.
- Sometime later the pigment epithelium via a special transporter transports the trans-retinal out of the outer segment into the pigment epithelium. All-trans retinal turns into all-trans retinol which is the precursor for 11 - cis. (Vitamin A deficiency).

3.1.2.2.2 Detail 2 - Cones

- cone -opsin rather than rhodopsin
- BIG DIFFERENCE is there are three cone opsin leading to trichromacy color vision (hold your breath and wait).

3.1.2.2.3 So turn this mess into neural activity!

- cGMP is the critical stuff. Its level is controlled by cGMP phosphodiesterase. The activation of pigment molecules lead to the activation of cGMP phosphodiesterase.
- Amplification - 1 rhodopsin molecule leads to hydrolysis 100 transducin each activating a phosphodiesterase molecule which hydrolyzes 1000 cGMP. Thus 1 photon activates 10^5 cGMP;

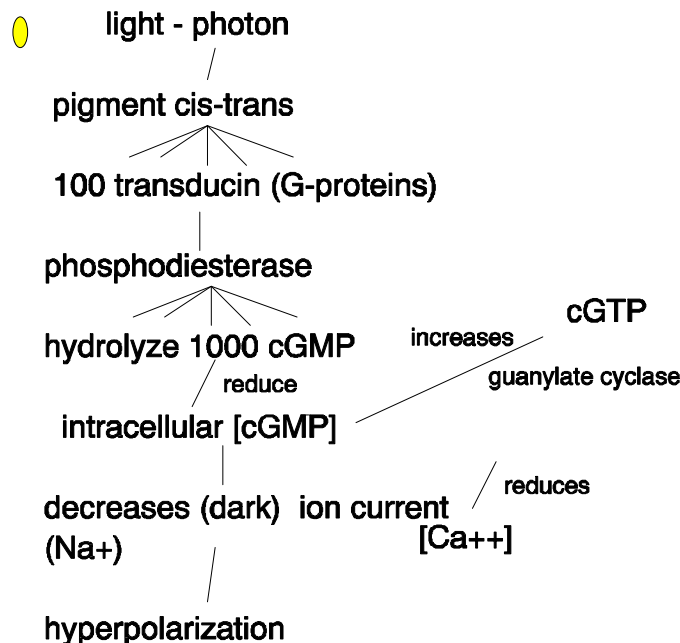


Figure 2 A low level view of transduction

3.1.2.2.4 What does the cGMP do?

- It changes membrane potential via cGMP gated ion channels (outer segment).
- Three cGMP molecules binds directly to the channels cytoplasmic part.
- The channel is a 63 k Dalton peptide with several membrane spanning units. cGMP opens the channel directly (not via a protein kinase). Located in outer segment primarily.

3.1.2.2.5 And what about the membrane potential (safe ground at last)

- Membrane potential primarily determined by a un-gated leak K^+ current hold membrane potential at -70mV (Nernst potential) (inner segment).
- In the dark, there are high levels of cGMP opening the cGMP gated channel which allows Na^+ entry leading to the dark current which moves membrane potential at -40mV. Constant flow of Na and K lead to lots of Na/K pumps.
- In the light cGMP decreases, cGMP channels close, Na current decreases, and membrane hyperpolarizes.

3.1.2.2.6 Light adaptation - mediated via Ca^{++}

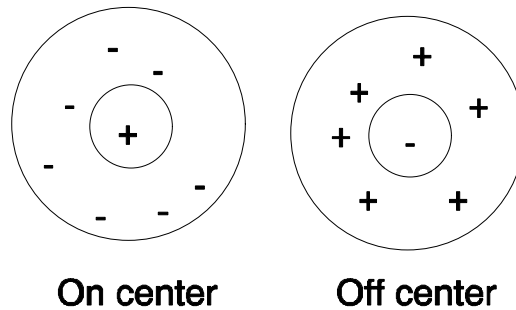
- Note increasing $[Ca^{++}]$ decreases cGMP via inhibition of guanylate cyclase that synthesizes cGMP from cGTP.
- $[Ca^{++}]$ enters with dark channel via cGMP activated ion channels
- Thus light decreases dark current and decreases intracellular $[Ca^{++}]$ which reduces inhibition of guanylate cyclase which increases cGMP which further reopens cGMP channels depolarizing membrane.

YECCH!*3.2 Laminar structure*3.2.1 Four layers -

- 1) Outer nuclear layer (rods/cones)
- 2) Outer plexiform layer (horizontal cells)
- 3) Inner nuclear layer (bipolar cells)
- 4) Inner plexiform layer (Amacrine)
- 5) Ganglion cell later

3.2.2 All these neurons are essentially interneurons and shapes the electrical signal en route to the optic nerve - lateral and direct pathways

- Recall that photoreceptors respond to graded potentials - same for horizontal and bipolar cells. Passive transmission of activity. Look at the pictures, the processes are small so there is little spatial attenuation.
- Bipolar neurons are center surround - cones connect directly to bipolar cells
- On center bipolars are depolarized while off center are hyperpolarized
- The surround are generated from horizontal connections (gap connections for specialized transmission)

This is a center surround

The center is from the rod/cone while the surround is from the horizontal cell (Fig 28-9).

3.2.2.1 Bipolar cells

Glutamate is the main transmitter here. Release by cone, which has differential effects on two types of bipolar cells. Some depolarized, some hyperpolarized (thus center on or off).

Rod/cones typically depolarized by dark current (remember!) thus constantly releasing glutamate. On-center bipolars are thus constantly hyperpolarized (v-v for off center). Light reduced dark current, hyperpolarizing rod/cone, reducing glutamate, depolarizing bipolar.

One transmitter - two actions -

On center - glutamate opens K^+ selective ion channels

Off center - glutamate open Na^+ channels

3.2.2.2 Horizontal cells

These synapse on the rod/cones, not the bipolars. They antagonize the response from the rod/cones. Thus activation of the surround can depolarize the horizontals, depolarizing the rod/cones which is exactly opposite what light would do.

The critical principle of lateral inhibition. NOW THIS IS IMPORTANT.

3.2.2.3 Bipolar cells activate ganglion cells

The bipolar cells make excitatory connections to the spiking ganglion neurons. Nice and simple. Depolarize a bipolar cell, depolarize the ganglion cell.

3.2.2.3.1 Amacrine cells

Spiking neurons - 20 morphological types, eight transmitters, little is know about role but thought to permit lateral interactions between ganglion neurons. This may lead to unusual retinal properties (e.g. orientation selective M-ganglion neurons - **RARE**).

3.2.2.4 Ganglion cells

- Business end of the retinal. It has fibers in the optic nerve that transmits to the lateral geniculate nucleus (LGN) via regular spikes. About 10^6 fibers for the entire visual image. Major compression of image.
- The properties of center surround...

- Multiple channels
- Enhancement of contrast. Zero crossing theorem of Marr.
- Multiple channels -
 - M ($P\alpha$)- on/off center, large cell bodies, large dendritic arbor, large receptive field (RECEPTIVE FIELD), magnocellular stream), coarse detail
 - P ($P\beta$)- on/off center, small cell bodies, small dendritic arbor, small RECEPTIVE FIELD, wavelength selective, (parvocellular stream), fine detail, color
 - K cells- overall light intensity

3.2.3 Log transform of light (dim to bright)

3.3 Color

Helmholtz, Trichromacy, Wait till we get to cortex

4 Lateral geniculate nucleus and other projection zones of retina²

4.1 Projection zones of the ganglion cells

- Midbrain pre-tectal area (pupillary reflex)
- Superior colliculus (eye movements) - other inputs also
- LGN

5 Optic Chiasm - split field representation

6 LGN - Parvo/magnocellular laminations

- M=1,2 P=3,4,5,6
- Maintained receptive field organization.
- Function - setting up initial maps for rest of cortex to use.
- Don't forget also rt/left eye representation.

7 Primary visual cortex³

7.1 Retinotopic map - 2DG studies.

7.2 basic summary of circuits

1. magno inputs into 4C α
2. parvo inputs into 4C β

² base on chapter 29 of KJS

³ base on chapter 29 of KJS

3. outputs via layer 2
4. intra-cortical circuits

7.3 *properties of neurons in VI*

1. retinotopic mapping
 2. orientation tuning
 3. ocular dominance
 4. end-stopping
- Critical ORIENTATION selectivity
 - Orientation columns
 - Ocular dominance.
 - Sub-structure of v1, blobs/inter-blobs columns, maps in maps
 - cytochrome oxidase blobs.

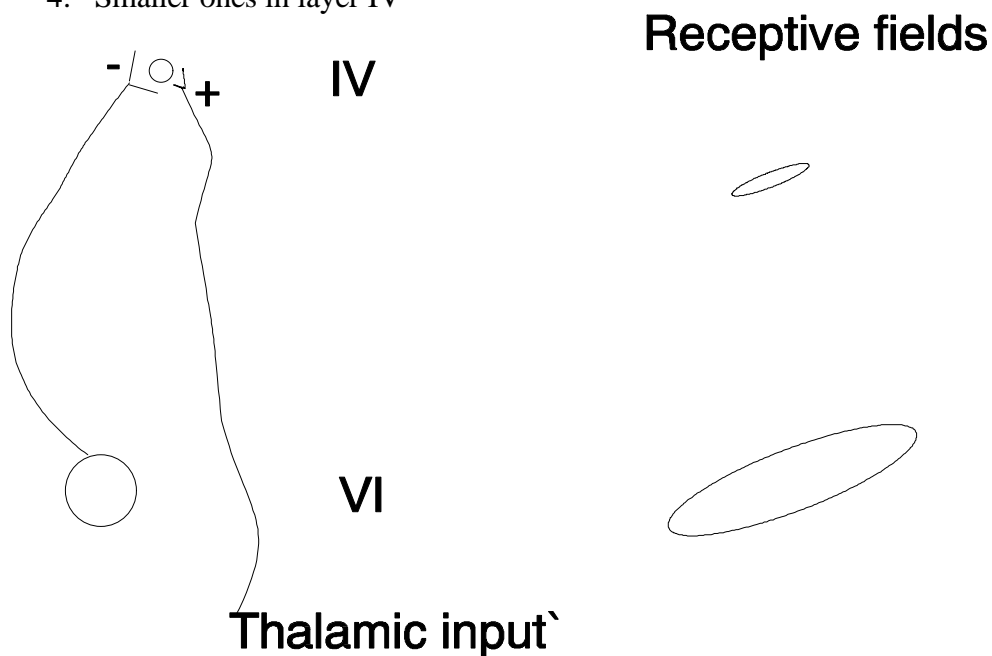
7.4 *Development of ocular dominance- Wiesel's work*

- Critical period for development of ocular dominance

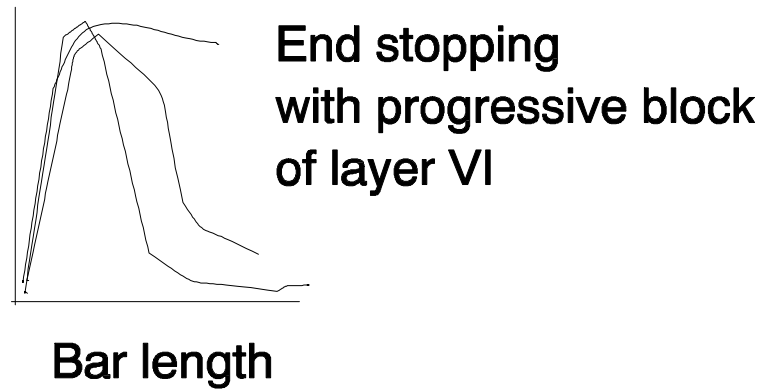
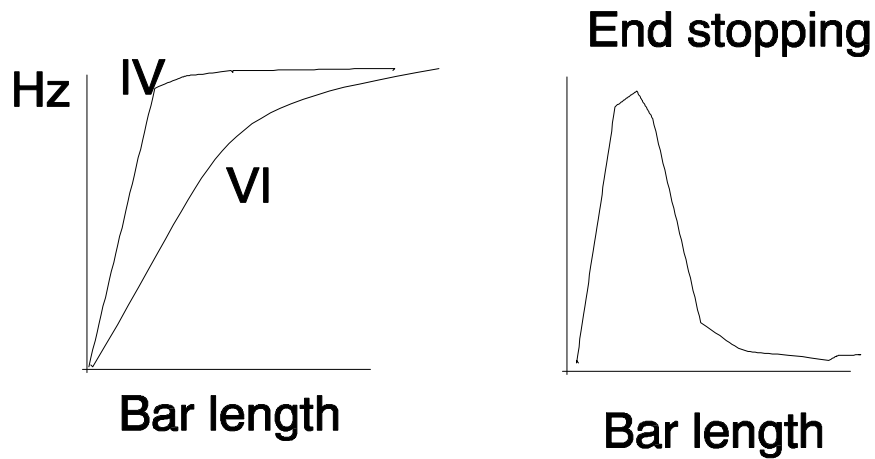
7.5 *Laminar structure*

7.5.1 The end-stopping story

1. Direct projections from layer VI to IV
2. GABAergic neurons
3. Larger receptive fields in layer VI
4. Smaller ones in layer IV



End stopping is caused by layer VI neurons blocking layer IV responses to longer bars



What is the functional use of end-stopping cells? Can be used for obvious line length or alternatively for measuring curvature.

8 V2

8.1 Functional architecture

1. primarily receives its inputs from V1
2. cytochrome oxidase patterns of thin and thick stripes

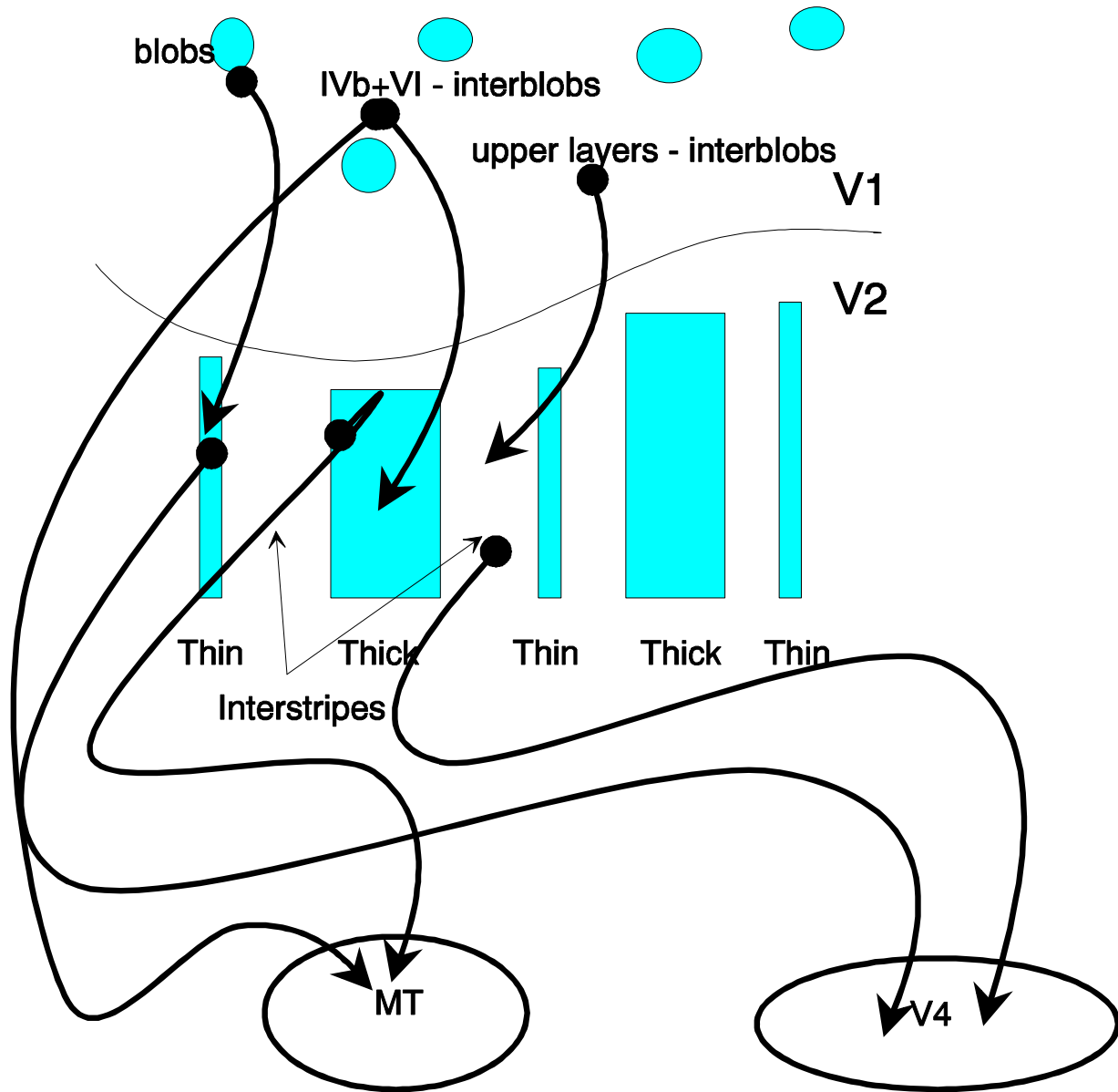


Figure 3 The connections amongst areas

8.2 Different properties in the stripes

1. thin stripes- color
2. interstripes - orientation, binocularity, color
3. thick- motion, orientation, binocularity

9 Extra-striate cortex (pre-striate, circumstriate)⁴

9.1 Two or three pathways -

- what and where -> motion, depth/form, color
- What defines a visual area? - borders, representations (Van Essen)
- Plethora of representations.
- Putting it back together - binding problem

9.2 Some visual functions

- Motion - middle temporal area, map of motion within retinotopic map
- (Albright), aperture problem, hierarchical underlie more complex motion
- analysis
- Binocular vision - combining the images (disparity tuning)
- Color - color constancy - three cones, V1 tuning,
- Form - face cells
- Space - combination of eye and retinal position parietal lobe function

10 Siegel Questions for Vision Lecture

Essay question 1) Anatomical feedback connections are found throughout the visual system, however little evidence as to their functional role is known. Review the electrophysiological, anatomical and behavioral literature as regards this question and suggest experiments to further test this hypothesis.

Essay question 2) Describe a particular loss of visual function that is seen with either retinal, sub-cortical or cortical damage in terms of its history. (Go back at least to the early 1900's preferably to the 1800's -- additional points will be given for older citations!). Also describe the loss of visual function in the regions involved and the etiology of the disease, Determine what high technology and expensive imaging technologies (PET, MRI, BEAM) tell us that we didn't know before in terms of the understanding of the locus of damage. Describe strategies that brain-damaged individuals can use to circumvent the difficulties. A non-inclusive list of syndromes is: stereoscopic blindness, achromatopsia, agnosia, alexia, inability to recognize faces, disconnection syndromes, motion blindness, parietal syndrome, ad nauseum.

Essay question 3) Unbelievable as it may seem, people can "see" without an occipital cortex. Research blindsight (history etc.) and use it as a vehicle to discuss the role of sub-cortical structures (LGN, other thalamic nuclei, colliculus). If you feel brave, discuss what the philosophical implications are.

Essay question 4) Another amazing fact: sight can be restored to the blind. Under certain conditions, removal of cataracts that were present from early in life result in a restoration of vision. Can these persons see? What is perception anyway?

⁴ base on chapter 30, 31 of KJS

Essay question 5) Visual Cortex is often considered to function independently of sub-cortical structures, other than the lateral geniculate nucleus. Is this a reasonable assumption? Discuss evidence for or against this idea? Provide a definitive experiment to examine this issue.

Essay question 6) Much is now known about the microcircuitry, electrophysiology and function of the retina. Choose one set of neurons (not the receptors) and discuss how the understanding of molecular and cellular details helps the understanding of their role in the computations thought to be performed in the retina. Suggest an experiment to further test this.

Siegel Readings

Kandel, Jessel & Schwartz

Chapter 28 - The retina

Chapter 29 - Central Visual Pathways

Chapter 30 - Motion Depth & Form

Chapter 31 - Color Vision

Optional reading:

Van Essen et al. Modular & hierarchical organization of extrastriate visual cortex in the macaque monkey. CSH Symposium, 1990

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