Retinal Prosthetic Systems for Treatment of Blindness

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Neurological Disorders

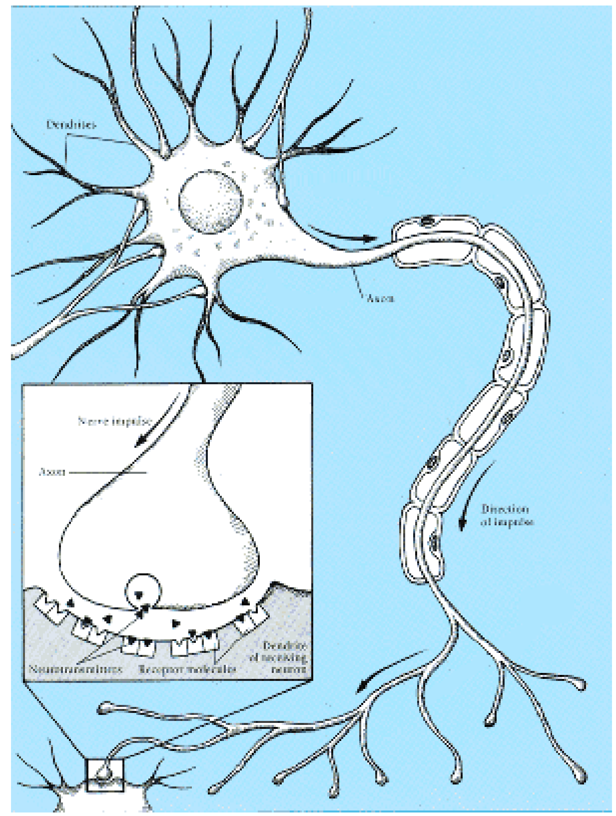
- The human nervous system, when damaged, does not heal well, if at all
- Stroke, Cognitive Impairment, Blindness, Deafness, Chronic Pain, Parkinson’s all are significant, disabling diseases affecting 100’s of millions of people worldwide, costing billions of dollars, and immeasurable misery
- Implantable neural stimulators have successfully treated some of these conditions

Overview

- What is a nerve and how do we electrically connect to a nerve to control activity?
- Current clinical systems for neural disorders
- Retinal Prosthetic Systems
  - Brief history of electrical stimulation for blindness
  - Current clinical prototypes
  - Future of retinal prostheses

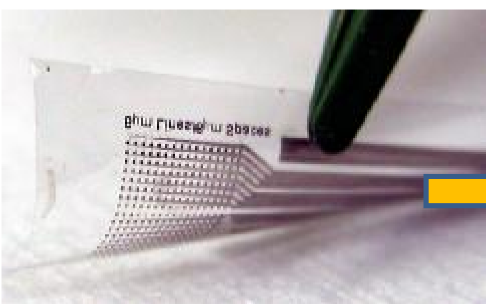
Nerve Anatomy and Physiology

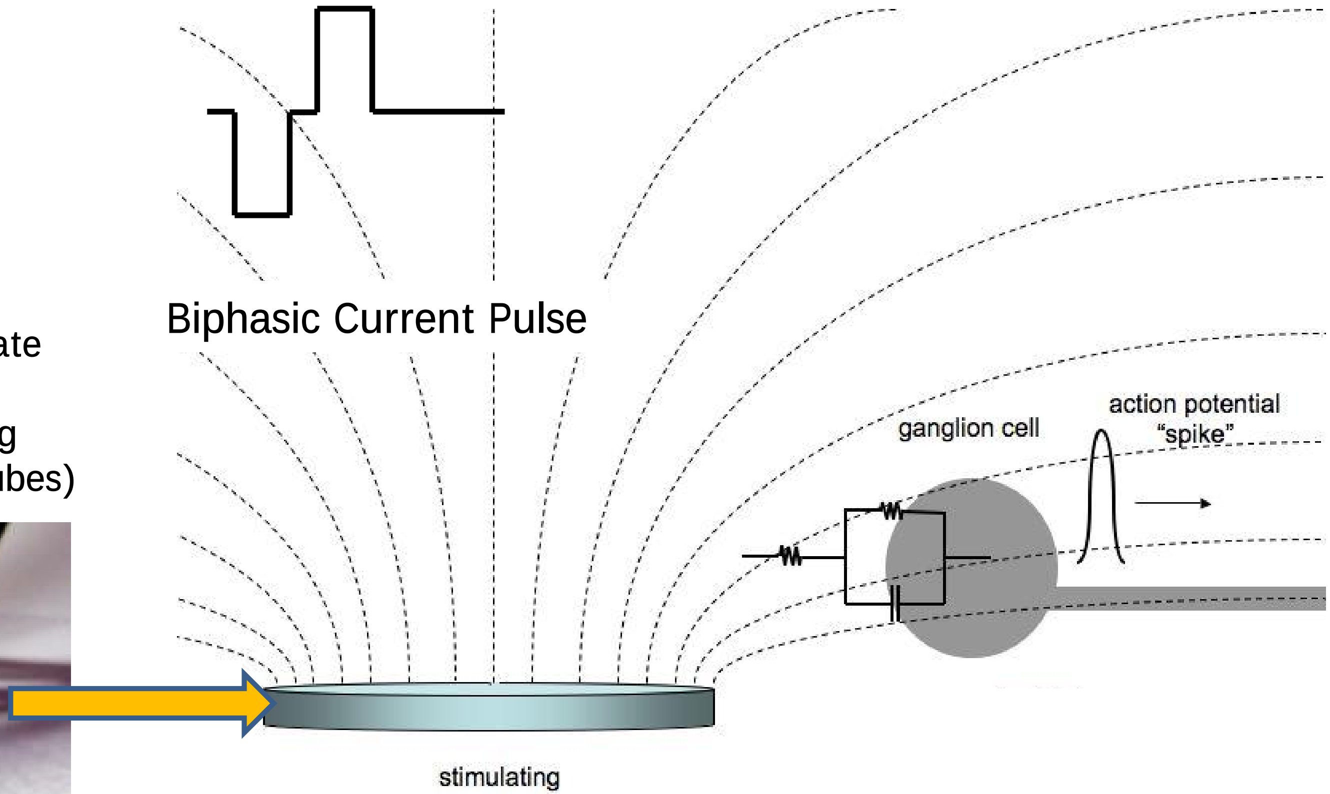
- Common features
  - Dendrites, soma, axon
- Synaptic connection to other nerves
- Cell membrane
  - Electrical potential
  - Variable membrane conductance used for signal propagation



Electric fields applied by microelectrode can activate nerve cells

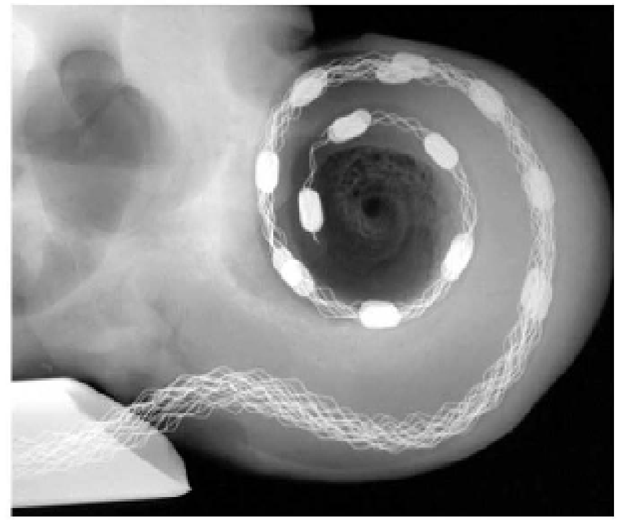
Electrodes are made of
• flexible or rigid substrate
• conducting material
(noble metal, conducting polymer , carbon nanotubes)

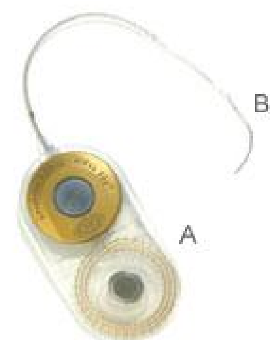




Cochlear Implants

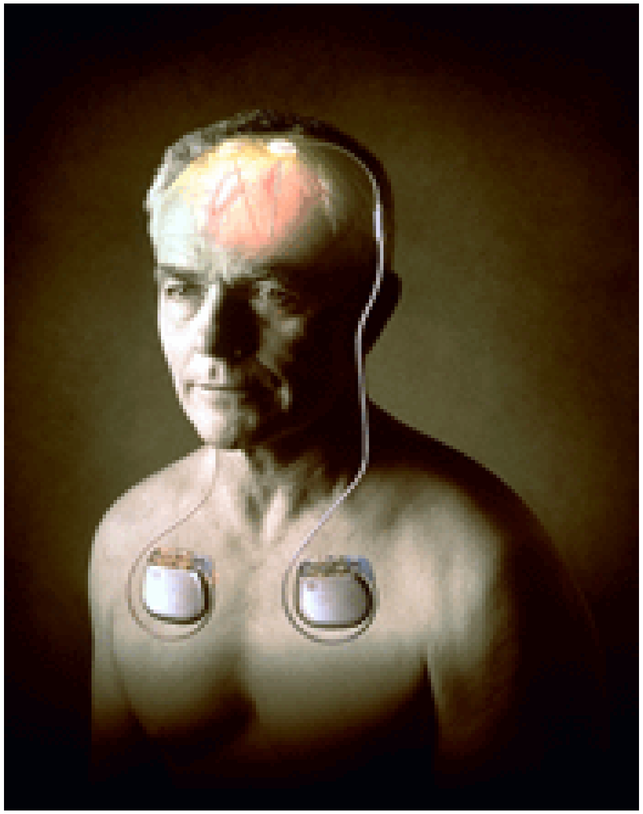
- Today's implants stimulate the cochlea at up to 32 locations, but usually use fewer (4-8)
- Best subjects can talk on the telephone (i.e. no lip reading)



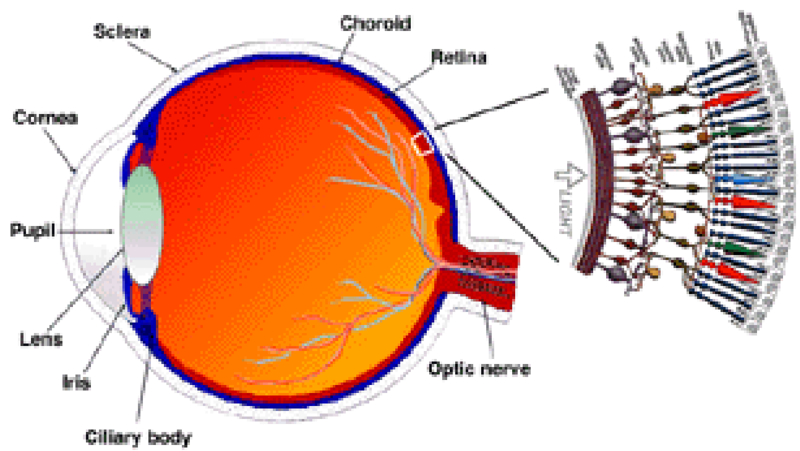


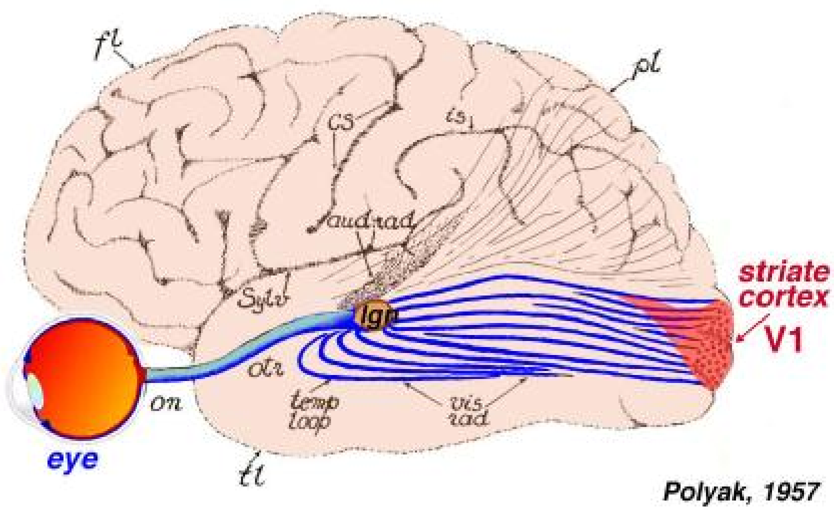
Deep Brain Stimulation

- Thalamic stimulation to treat movement disorders (dystonia, chorea, tremor), approved single side 1997, double sided 2002
- Remarkable results, simple device



Human Visual System and Retinal Blindness



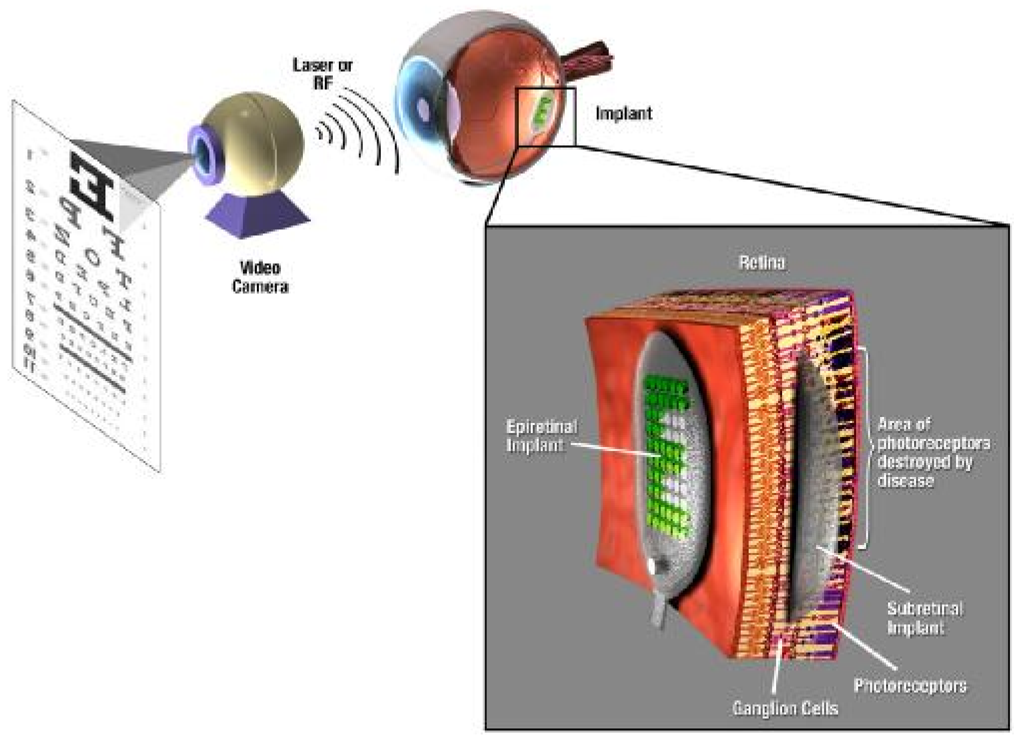


Webvision, Kolb, Fernandez, and Nelson, 2003.

- Retina is a light sensitive neural network
- Diseases such as Retinitis Pigmentosa (RP) and Age-related Macular Degeneration (AMD) primarily affect the photoreceptors, are both presently incurable, and render 100,000s blind each year
- Implants have been tested in visual cortex, optic nerve, and retina

Retinal Prosthesis
Systems Level Description

- External camera/image processor detects image
- Telemetry link between external and implanted un
- Implanted unit recovers power and data
- Implanted unit applies commanded stimulus pattern to the retina via a microelectrode array



LeRoy's electrical stimulation of a blind person - 1755

- Brass wire wound around the head
- Return electrode attached to right leg
- Charge stored in primitive capacitor (Leyden jar), then discharged through the head
- Blind subject saw a "flame rapidly descending"

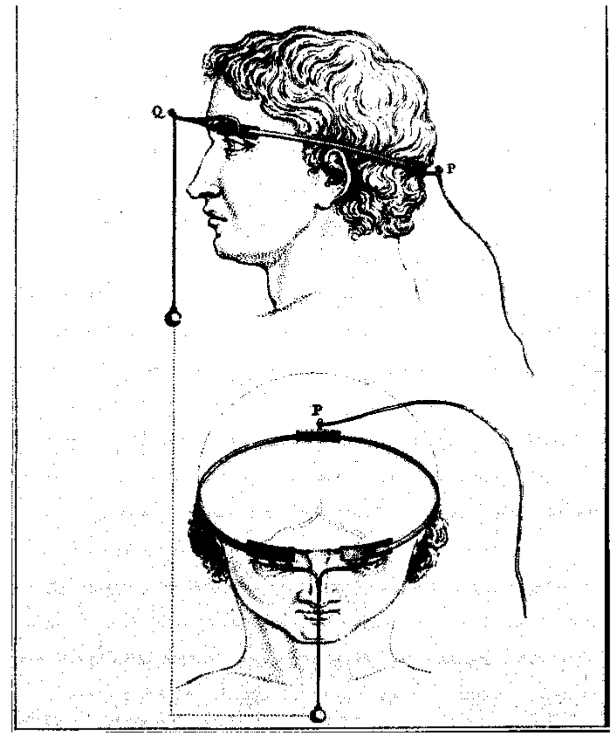
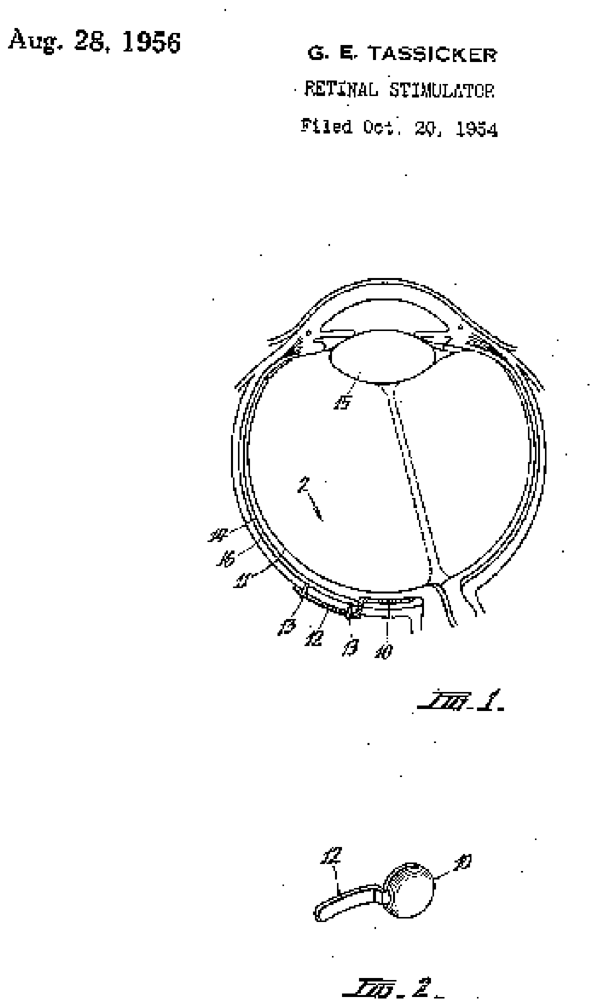
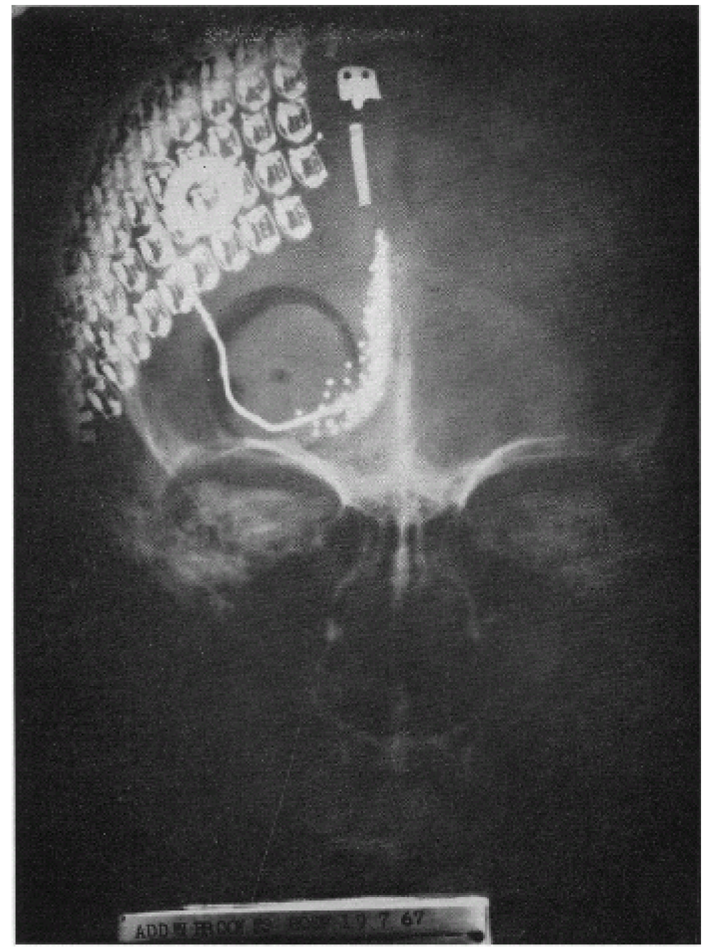


Figure 1. The electrodes (possibly the first bioelectrodes designed specifically for human stimulation) of Charles LeRoy in 1755.[2] They were connected to a Leyden jar, the first capacitor, which had been invented recently in Holland. It can be seen graphically that the then-known central visual pathway from the eyes to the chiasma where the two optic nerves join is correct. The rest of the path, a single bundle to the occipital region, is not correct. The actual path including optic tracts, lateral geniculate nuclei, and optic radiations was discovered a century later with the development of histological methods. It is interesting that at that time it seems to have been assumed that vision was seated in the back of the brain. From reference 2 from the Bancroft Library, Berkeley, CA.

Marg., Optom. Vis. Sci., 1991

Early Implants

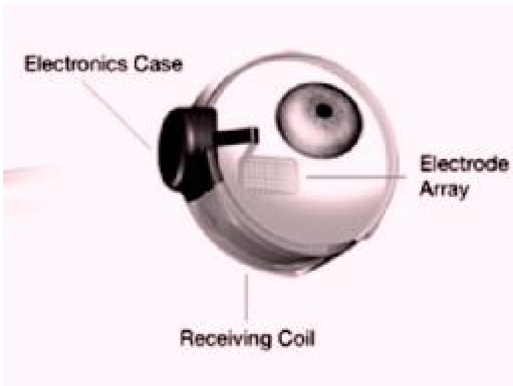


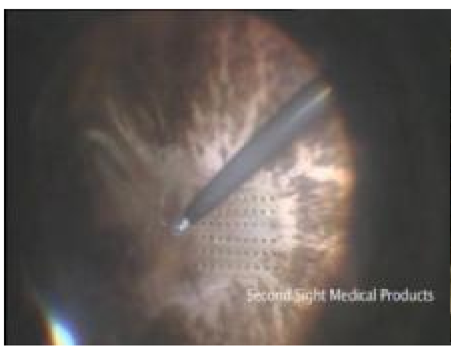


Retinal Implant Surgery

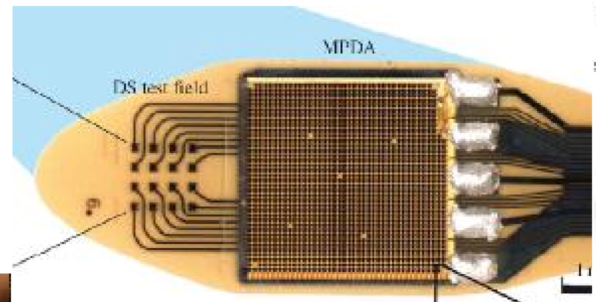
Retinal Prosthesis Clinical Trials

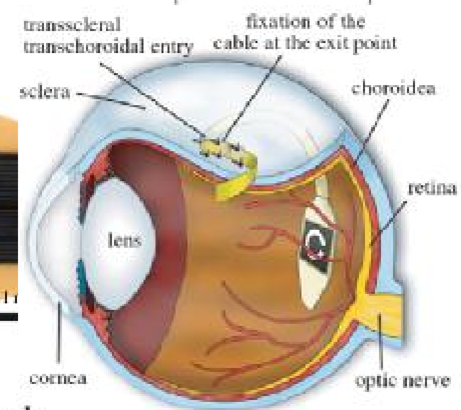
Argus II – Second Sight

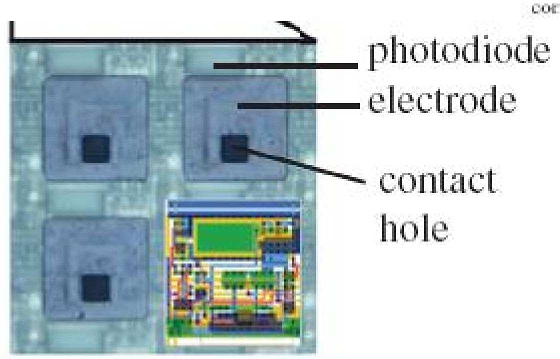




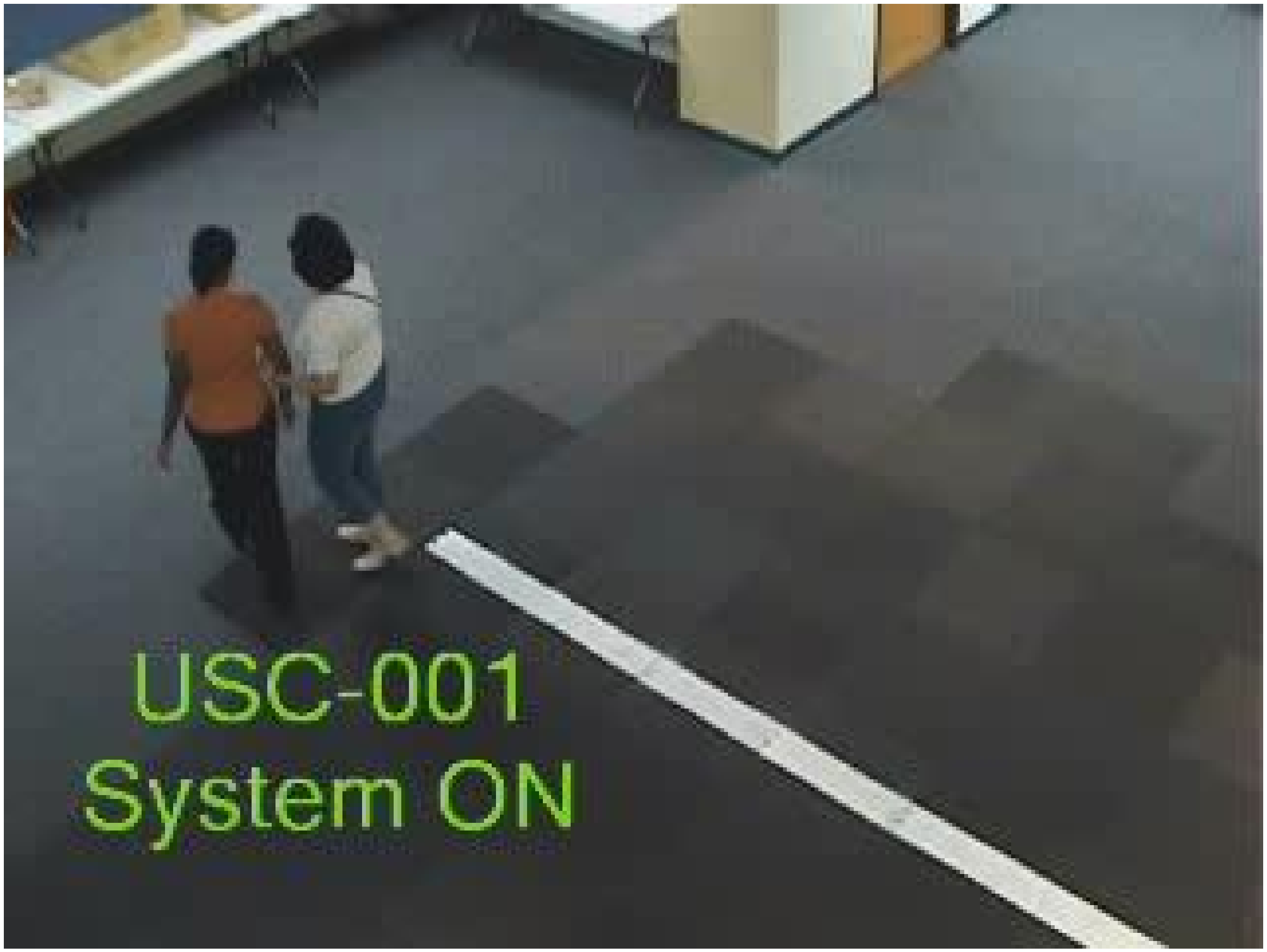
Alpha IMS – Retina Implant



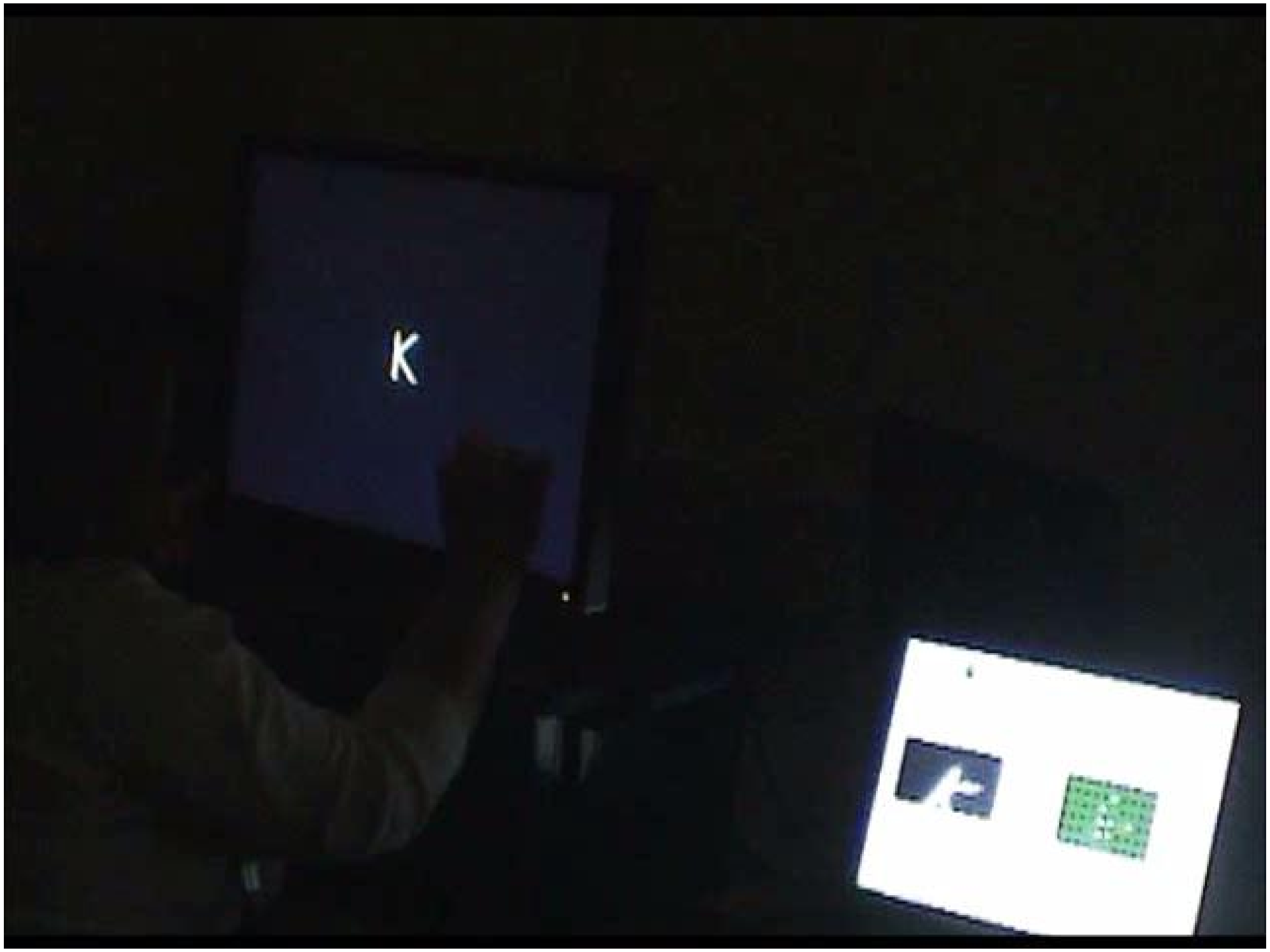




Mobility Testing



Letter Reading

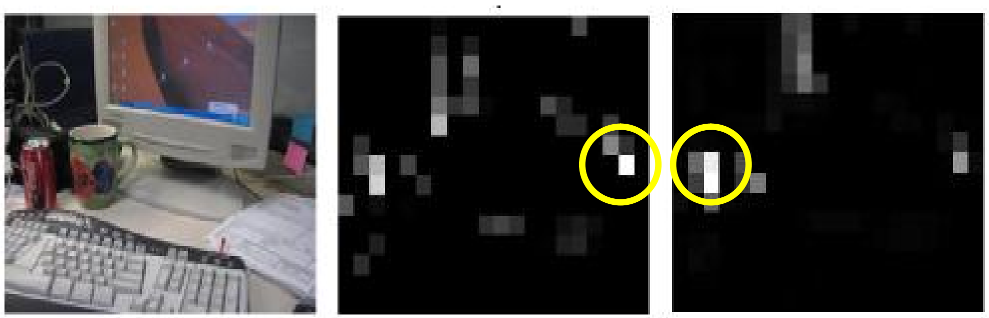


Summary of Clinical Trials

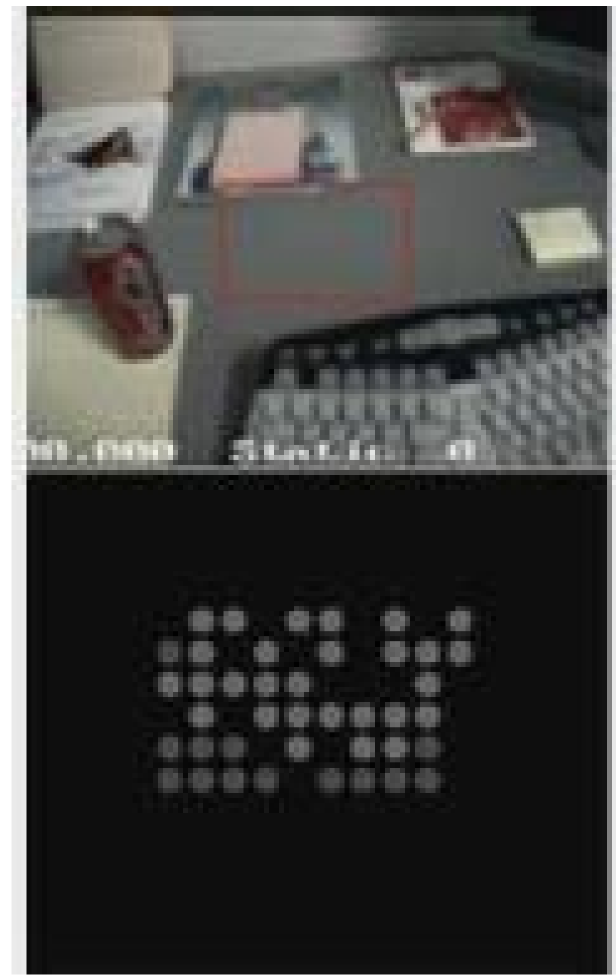
- Devices appear to be well tolerated by the eye, with only minimal adverse events
- Second Sight and Retina Implant have similar functional results
  - Best subjects are reading letters
  - Visual acuity: RI 20/1000, SSMP 20/1200
- How can we improve results
  - Make current device more effective
  - Make the implant higher resolution

Smart Image Processing

- Use existing video stream to provide more information
- Saliency Algorithm (Itti, et al)
  - Based on primate visual system
  - Highlights “salient” objects based on color, orientation, intensity
  - Top down information improves performance of algorithm



Dr. Neha Parikh, Dr. Laurent Itti



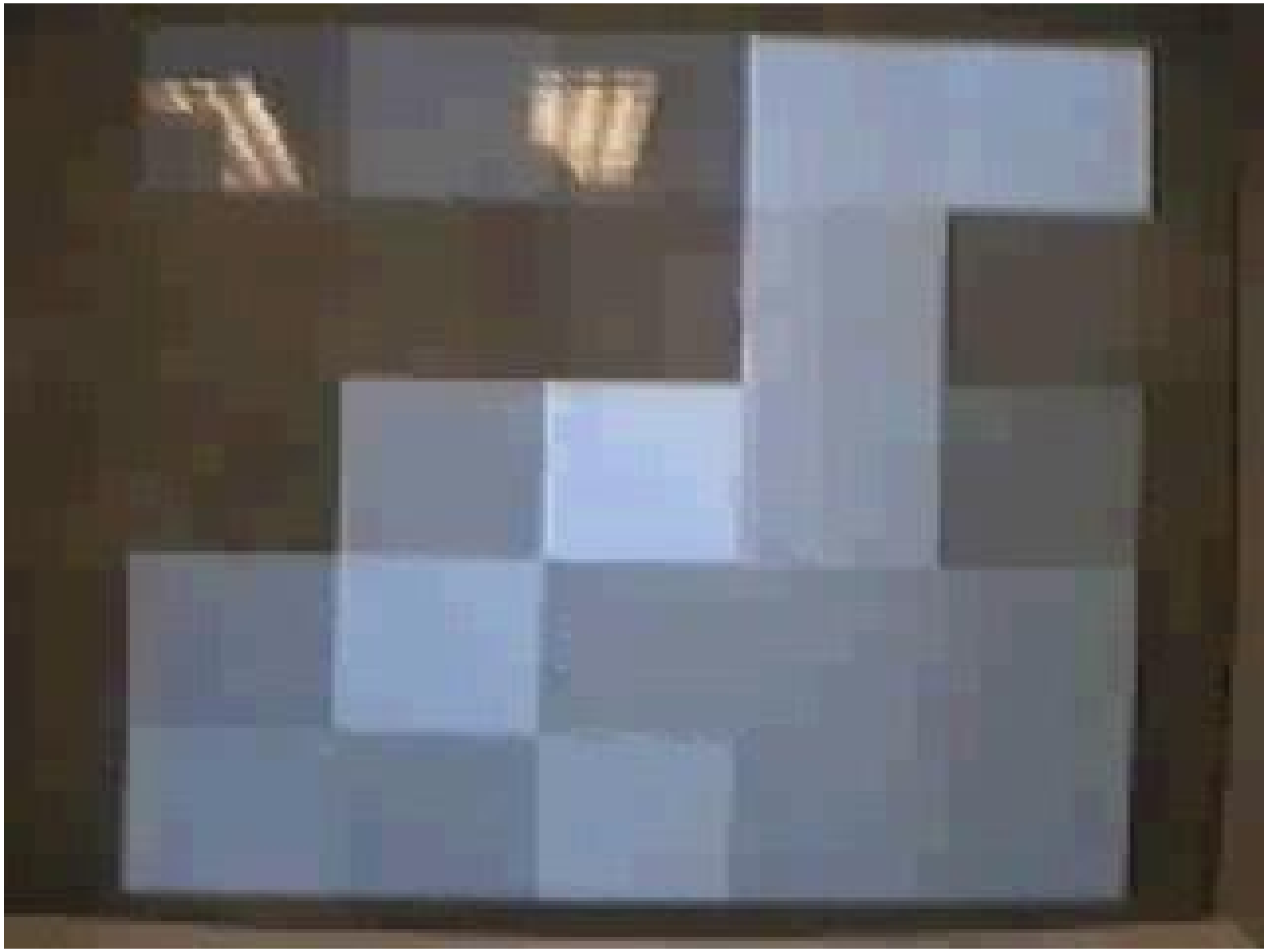
Simulated Artificial Vision

Smart Image Processing

- Mobility and orientation are difficult for blind
- Use computer vision to identify local map and define clear path
- Can work in conjunction with wireless mapping databases
- Possible for use as wearable system for low-vision in general

Dr. Vivek Pradeep, Dr. Gerard Medioni

Simulation of High Resolution Artificial Vision

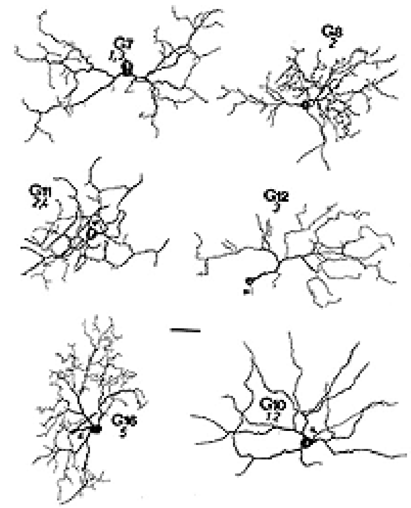


Needs for High-Resolution Retinal Prosthesis

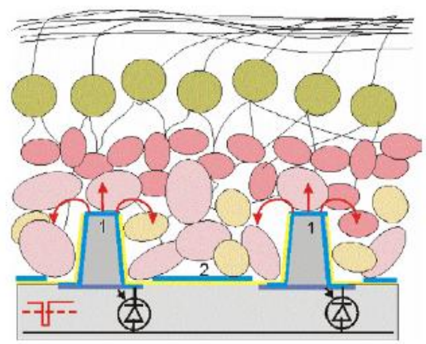
- Technical
  - Hermetic packaging
  - Dense electronics
  - Smart image processing
- Biological
  - Understanding effects of blindness on the brain
  - Selective stimulation
    - Closer contact between electrode and retina
    - Optogenetic stimulation

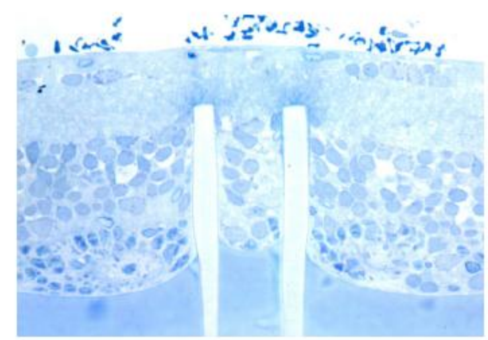
Selective Stimulation
Getting Electrodes Closer to Cells

- 18 morphologically different retinal ganglion cell types in primate retina
- With large surface electrodes, simultaneous stimulation of “on” cells and “off” cells
- Penetrating electrodes may allow more selective stimulation



webvision.med.utah.edu

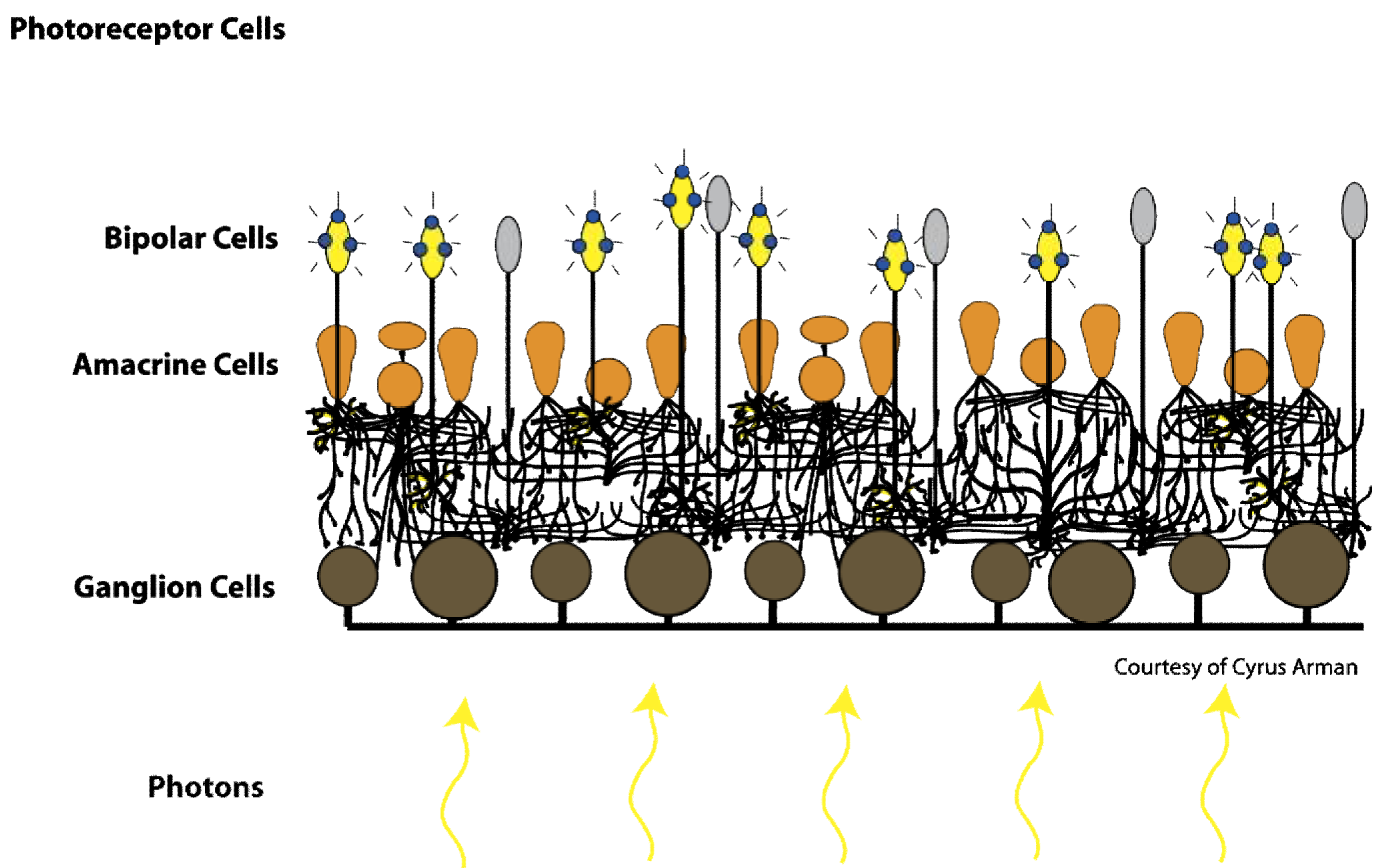




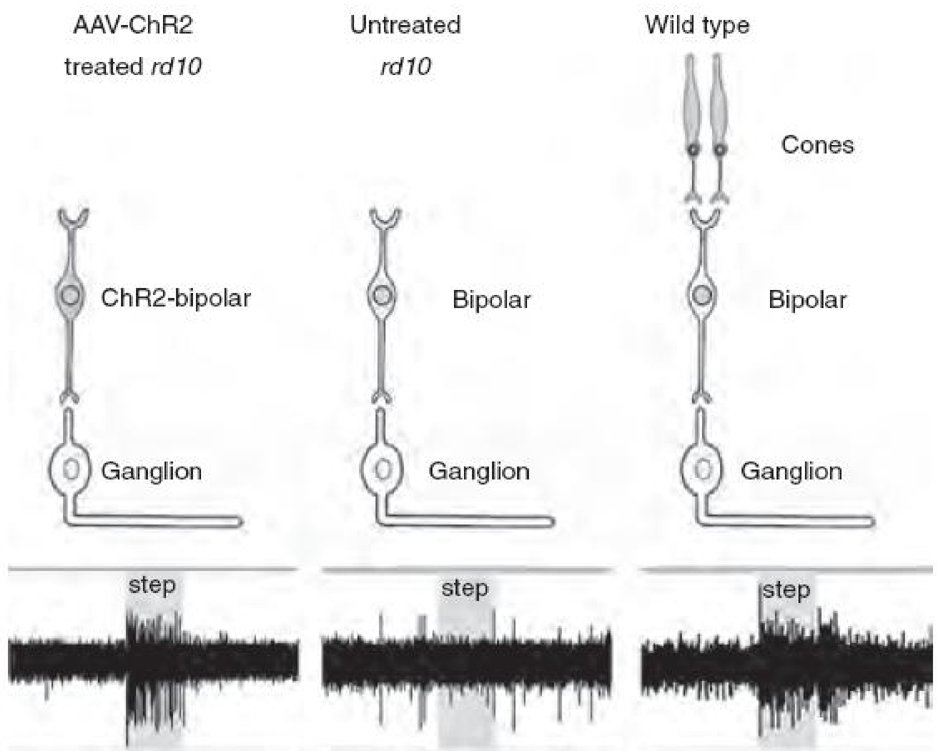
Palanker 2005

Alternative to electrical stimulation

How the ChR2 approach Works



Neural responses generated by ChR2



Threshold is 4 orders of magnitude above cone threshold (bad result, needs to be more sensitive to light)

Courtesy Alan Horsager

Summary

- Clinical trials show some promise
- Technology improvements needed in every area for high-resolution implant
- Strategies needed for optimizing the implantees visual task performance
- How much benefit is enough to change clinical practice?
  - Psychological vs. mobility vs. detailed form perception

Retinal Prosthesis Team Members

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